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PAPERS PRESENTED AT THE SIXTH SHORT COURSE IN COAL UTILIZATION

HELD AT THE

UNIVERSITY OF ILLINOIS
MAY 21-23, 1941

PRICE: FIFTY CENTS

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FOREWORD

The sixth Short Course in Coal Utilization held at the University of Illinois was offered by the College of Engineering through the Department of Mining and Metallurgical Engineering.

The purpose of the Short Course was to present an educational program of technical and practical information pertaining to coal and its efficient utilization for the benefit of those engaged in mining, preparing, marketing and using coal, as well as for those manufacturing and distributing machinery for the preparation and utilization of coal.

SHORT COURSE ADMINISTRATION
1941

M. L. ENGER, Dean of the College of Engineering

H. L. WALKER, Acting Head of the Department of Mining and Metallurgical Engineering

H. P. NICHOLSON, Assistant Professor of Mining Engineering, Director of Short Course

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I. THE COMPETITIVE POSITION OF ILLINOIS COAL

WALTER H. VOSKUIL*

The Illinois coal industry competes principally in six states of the Upper Mississippi Valley with coal from the Appalachian fields, from Indiana, Kentucky, and Arkansas, with fuel oil, and with natural gas imported from the Texas Panhandle and Hugoton fields and from the Monroe field in Louisiana. The approximate amount of fuel used in these states (Indiana, Illinois, Wisconsin, Minnesota, Iowa, and Missouri) is the equivalent of 111 979 000 tons of coal, divided among the fuels as follows:

	Tons
Coal, all-rail, industrial and domestic	54 500 000
Lake cargo coal	28 850 000
Railroad fuel, approximately	15 000 000
Total coal	92 350 000
Fuel oils (49 315 000 bbls)	12 329 000
Natural gas (183 000 million cu. ft.)	7 300 000
Total, all fuels	111 979 000

Shipments from the Appalachian fields include from 4 to 5 million tons of by-product coal used in coke manufacture. This is non-competitive with Illinois coal since the latter is not suitable, by itself, for the manufacture of metallurgical coke. The principal competition between Illinois and eastern coals is in the domestic fuel market. The low-volatile coal field of West Virginia is a particularly heavy contributor to the Chicago markets. Coal for industrial and public utility use, on the other hand, is supplied mainly from Illinois, Indiana, and western Kentucky fields.

Fuel oil consumption in the Illinois coal market area represents about 11 per cent of all fuel used. About 60 per cent of this oil consumption is used in domestic and commercial heating, and this is the only use for fuel oil which shows a continued growth. Fuel oil finds its competitive position strongest where factors other than heating value are of importance to the consumers, and in convenience of handling.

Natural gas, while the smallest contributor to the fuel supplies of the area, is nevertheless still growing in importance. An important element in the competitive position of natural gas in the domestic heating market is the ability to dispose of surplus gas supplies in the

*Mineral Economist, State Geological Survey, Urbana, Illinois.

industrial market under the cut-off clause in the gas contract. This clause gives the gas company the privilege of cutting off the supply of gas upon short notice. Under this arrangement, the daily and seasonal demands of the heating market can be supplied without shortage, while at the same time, extreme fluctuations in the flow of gas through the supply lines is prevented.

II. STOKER SALES AND REGAINING LOST TONNAGE IN ST. LOUIS

J. HAROLD HANSEN*

St. Louis has been acutely conscious of the smoke evil for more than fifty years. About forty years ago an ordinance was enacted, directed at industrial smoke, with little, if any, result.

A personally financed campaign, to obtain evidence of violations by industry, was started in 1911. Industry at that time was adopting smoke abatement methods, but practically no improvement was noted. Realization that residences and apartment houses contributed an even greater total amount of smoke than factories and locomotives was the result. In all attempts at smoke abatement up to 1933 the official policy was one of education and persuasion rather than compulsion, and the public saw no apparent improvement. The first ordinance which placed restrictions on the fuel used was passed in 1937, but the result obtained by this was not satisfactory to the press and the public.

The Smoke Elimination Committee was appointed in December of 1939, and after several months of intensive study decided that the solution must lie in providing smokeless coal for all hand-fired furnaces, and permitting the use of high-volatile coal only when automatic stokers made possible its use without smoke, and that the sale and use of high-volatile coal in furnaces not provided with stokers must be forbidden under penalty of law. An ordinance to this effect was drafted and passed in April, 1940. The committee put all the teeth possible in the ordinance, and a rigid enforcement program was initiated.

As a result, the producers of high-volatile coals now find the St. Louis market lost to them on the hand-fired sizes. However, these producers now have a formidable ally.

This ally is the group in the stoker industry which comprises stoker sizes from 6 pounds to 1200 pounds of coal feed per hour (classes 1 to 4). As an industry group, it was born about 20 years ago. Up to January, 1941, approximately 740 000 stokers had been installed in the United States, using a total of over 23 000 000 tons of stoker coal per year. These figures, published in the January, 1941, issue of *Coal Heat*, are based on reports to the Department of Commerce, and indicate an average annual consumption of 31.8 tons per year per stoker in this group.

*Mechanical Superintendent, Iron Fireman Corporation, St. Louis, Missouri.

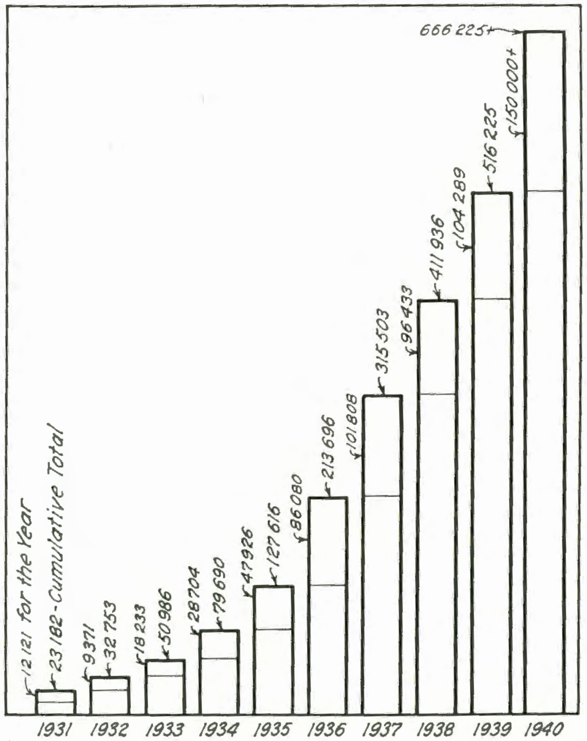

FIG. 1. CUMULATIVE STOKER SALES 1931-1940

Now let us look at the St. Louis situation. During the years 1938, 1939, and 1940, the only years for which records are available, there were 11 769 group 1 to 4 stokers installed in St. Louis. These 11 769 stokers account for an increased consumption of stoker coal to the amount of 374 253 tons annually.

Stokers of this group, however, have been sold in St. Louis for at least fifteen years and the best estimates of those in the stoker business in St. Louis show there were approximately 10 000 group 1 to 4 stokers installed prior to 1938, thus giving a total of 21 769 group 1 to 4 stokers now operating in St. Louis.

We apply the national figure of 31.8 tons of coal per stoker, and thereby determine that these stokers are accounting for a total consumption of 692 254 tons of Illinois coal per year. This tremendous tonnage is practically assured to the Illinois operators for years because of the many advantages of stoker firing and the owner's investment in equipment.

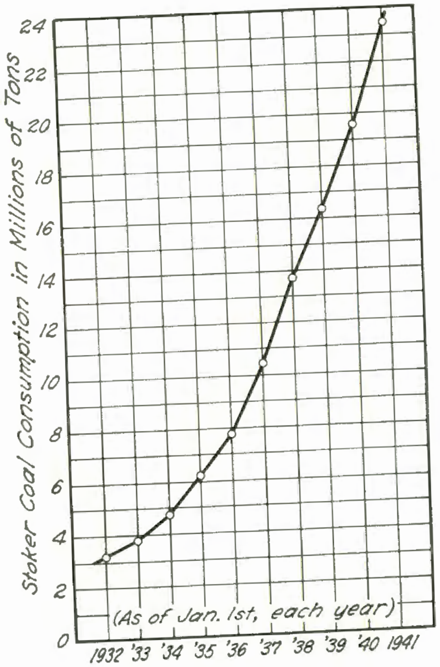

FIG. 2. ANNUAL STOKER COAL CONSUMPTION

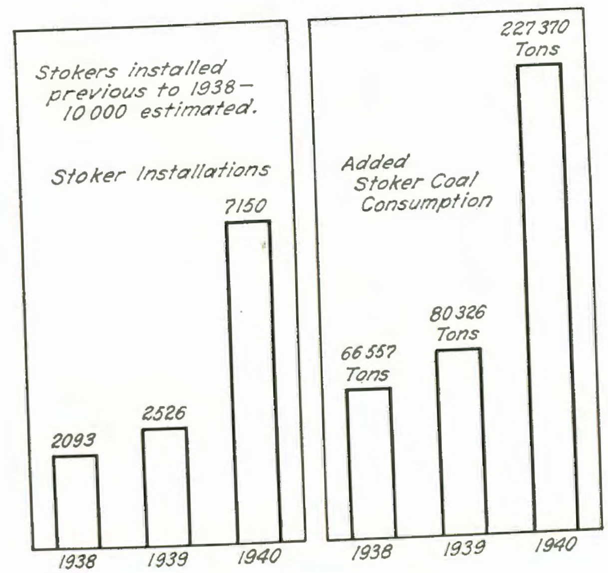

FIG. 3. STOKER INSTALLATIONS AND STOKER COAL CONSUMPTION FOR 1938, 1939, AND 1940 IN ST. LOUIS

Reliable records show that in 1940 the following quantities of smokeless fuels were shipped into St. Louis. The following table shows the breakdown by types:

Smokeless Fuel Shipped into St. Louis in 1940

	Tons
By-product coke	150 000
Petroleum coke	85 000
Carbonite	80 600
Solarite	50 400
Arkansas, Oklahoma, and West Virginia Smokeless	775 000
	1 140 000
Less Carbonite and Solarite	131 000
Lost tonnage	1 009 000

Carbonite and Solarite are processed from Illinois coals, and do not represent lost tonnage.

The balance of the smokeless fuels imported into St. Louis in 1940 adds up to 1 009 000 tons. This tonnage could all be regained by the Illinois producers if group 1 to 4 stokers were installed in St. Louis to the total number of about 30 000 additional stokers, or if some other device or method were perfected for the successful burning of Illinois coal smokelessly. This is a big job, and it can only be accomplished with the wholehearted cooperation and support of the coal industry.

III. TECHNICAL DEVELOPMENTS IN THE COAL SPACE HEATER

H. A. Eggert*

The past decade has seen an increasing amount of activity in the development of the space heater, and, particularly in the last several years, this pace has accelerated. To the layman, it would seem that any progress that has been made has all been of recent origin. Actually, a study of the files of the patent office will show that there has been almost constant activity and, peculiarly enough, most of the basic work was done prior to the turn of the century. It is true, however, that the increasing sale and use of the oil space heater has focused attention on the necessity for improvements in the coal heater.

Much of this research has been done by individuals outside the coal trade and by some university laboratories, although there has been an increasing amount of time and money devoted to the problem by some of the larger coal companies and by their associations in the last few years. While there have been several lines of approach by the various organizations, a summary of them would indicate about four major objectives.

Several of the research endeavors have had as their major goal the elimination or diminution of smoke, and certainly it can be listed as of prime importance, not only from a public welfare standpoint, but also from a more selfish one in view of the emphasis placed on the smoke campaigns conducted by public agencies and by our competitive fuels.

Of equal importance has been the effort to enlarge fuel bed capacities, with one (or both) of the following objects in view: either to provide a large enough bed to carry overnight, or to provide an adequately large amount of fuel to serve as a reservoir to be fed as required to the firing zone.

With the standard of living increasing steadily, there has been an increasing demand for better temperature regulation. In the case of hand-fired furnaces and boilers, I would venture a guess that there are far more units now equipped with temperature control than there are without. It is natural, therefore, that the coal space heater should be getting some much needed but belated attention on this score as well.

*Sales Engineer, Old Ben Coal Corporation, Chicago, Illinois.

More or less as an off-shoot of the previous objective, is that of providing better heat distribution throughout the dwelling. This problem has been even further emphasized by the tremendous growth in low-cost housing, both public and private.

From the viewpoint of customer satisfaction, one of the most important considerations is that the fire hold overnight. In fact, to achieve parity with competitive fuels, capacities should be enlarged sufficiently to necessitate re-fueling only once in 24 hours.

To reach this goal, most experiments have followed the lines laid out by the older types of hard coal heater, in the provision of a magazine for fuel storage. However, the coking and swelling characteristics of bituminous coals have presented a problem to contend with very different from that presented by the non-coking anthracite. The difficulty has been to overcome the tendency of these deep fuel beds to arch over and burn out underneath. In some designs an attempt has been made to keep the reservoir cool so that the reserve fuel remained in its natural state until just before it was due to be ignited. This worked all right as long as low fires were maintained, but on heavy firing it was found that heat would work its way back into the upper chamber and the reserve fuel became unmanageable, unless manipulated by hand. To keep this chamber cool, resort was had to either air cooling or water cooling.

One other method used was to slot the sides of the fire pot so that deep fuel beds could be carried without blocking off the draft. Another more recent method has been to provide flues so that deep fuel beds can be carried without blocking the passage of air through a dense fuel bed. In all these efforts the magazines have been of the open-top type; that is, directly connected to the stack. The result has been that the whole mass became ignited, defeating the reservoir principle, since the entire fuel bed became active. Where low rates of combustion have been employed, this has not been a serious objection; on high firing rates, however, such a large fuel bed under fire at one time has made it a difficult one to control.

In one recent design the magazine has been sealed off from the stack, so that there is no direct connection between the flue and the fuel bed. In this method the principle of the by-product coke oven is employed, in that the gas is driven off the fuel and the coke is fed to the firing zone by gravity. In this manner it is almost impossible for the entire fuel bed to become ignited, even on high firing rates.

There has been a general movement toward lining fire pots with fire brick, which serves two purposes. Not only does the fire brick protect the cast-iron or steel shells, but the heat-retaining quality of the fire brick has a tendency to help scorch the fuel bed away from the side walls, so that arching is minimized since the fuel bed does not so easily adhere to the side walls and hang up.

The increasing use of magazine type heaters has unquestionably answered one of the most vexing problems of the industry in that it has provided a means whereby it is now possible to carry fire overnight even under severe conditions.

Similarly, with regard to smokeless combustion, the magazine heater again offers the two best approaches to a solution of the problem. In most of the new type magazine heaters the fact that fresh fuel is not immediately ignited aids in minimizing the smoke evolved during any given period of time by spreading the active distillation of these gases over a greater length of time. In the underfeed space heaters, of which there have been several thousand sold, naturally, the smokeless performance has been assured by the very nature of the design. In using the by-product method, with a sealed magazine, the gases distilled after refueling are forced to pass through the coke bed so that conditions similar to those encountered in the underfeed stoker are approximated, and smoke is practically eliminated.

It has thus become possible to supply heaters today that burn a wide variety of coals of varying size and composition in a relatively smokeless manner.

While heat control has been more or less standard for some time in the larger types of burning equipment, strangely enough there has been but little effort to adapt it to the coal space heater although the manufacturers of oil and gas space heaters have used that as one of their principal selling points.

One of the first developments in control of burning rates was the barometric damper. Today this is practically standard equipment on underfeed stokers and on oil heaters, and there is a growing tendency to recommend them on the part of the coal space heater manufacturers also. While it is generally true that in chimneys to which space heaters are attached the draft is usually less than required rather than more, and while the barometric damper cannot increase draft beyond that available with no control, nevertheless, there are sufficient instances where draft varies over such a wide range that some form of maximum control is necessary to prevent wastage of fuel. This is particularly true of conventional heaters, where the emission of flame is just below the smoke collar.

Not only is the barometric damper a fuel saver but it can, under some circumstances, contribute to safety by checking the flame in the smoke pipe so that this pipe does not develop dangerous temperatures at the entrance to the chimney proper.

There has also been developed a type of check damper which is set out at some distance from the smoke pipe and is actuated partly by room air temperatures, and which has some tendency to keep the stove under control.

One other recent approach to the control problem has been an ash pit damper which is actuated by the temperature of the inflowing primary air. The theory behind this control is that room air is also the source of primary air for combustion in any space heater.

That being true, this device uses a tube, which is shielded on the stove side from radiated heat, to supply the primary air to the ash pit. Inside this tube is a damper operated thermostatically by the temperature of the incoming air.

One of the latest heaters on the market uses a bi-metallic coil attached to the side of the heater and actuated by the temperature of the heater shell. In this heater, which uses a check damper, both dampers are located adjacent to each other and the expansion and contraction of the coil operates a pair of levers which allow a uniform burning rate and a uniform jacket temperature to be maintained regardless of changing draft conditions or ash accumulations on the grate.

There is no reason why electrically operated room control apparatus cannot be used with space heaters, and experiments directed toward this end are now in progress so that an inexpensive device will be made available to this class of equipment.

The addition of forced circulation devices is of recent origin in the space heater field. When it is realized, however, that a furnace is nothing more than an overgrown stove, it is surprising that there has not been more progress along this line. There are a number of oil heaters on the market at the present time that use forced circulation with an electric fan, but so far such forced circulation for coal heaters is more or less in the initial stage. During the last several years, however, there have been several forced air fans put on the market for use as an auxiliary to space heaters. There are low velocity fans whose blades are designed to take a deep bite but not to create an excessive draft in the room. These fans have been very effective in throwing heat into pockets or into hard-to-heat corners, and are relatively inexpensive.

Second only to high standards of design and performance is the

matter of durability and appearance. To secure a heater that has a long life, one naturally must pay more money. To secure one with better appearance also involves a slight increase in cost. That it is a bad mistake to allow a prospective customer to buy a cheap coal heater, with limited life and antiquated appearance, in the mistaken notion that this man is then bound to burn coal, is borne out by facts. This same customer, who later has forgotten the cost, and only remembers the daily irritation of repeated fuelings and ugly appearance, is fallow ground for the oil heater salesman. The argument put forth to discourage efforts to sell better equipment is that it is a market of limited purchasing power. To refute this it is only necessary to refer to a breakdown of the sales of heaters in 1940. This shows that 57 per cent of the coal heaters and 76 per cent of the oil heaters were sold above $40.00. It further shows that 28 per cent of the coal heaters and 53 per cent of the oil heaters were sold in the bracket above $60.00. It will be noted that the oil heater, selling in the same market as the coal heater, is able to secure a much better price. Why? Because it has had convenience and appearance, even if it could not throw as much heat and did cost considerably more to operate.

With greatly improved coal heaters now on the market, offering greater economy and more adequate heat than those using competitive fuels, and with appearance on a par and durability superior, there is no reason why more coal heaters should not be sold in the upper brackets.

The many thousands of four- and five-room low-cost one- or two-story houses have created a demand for a low-cost heating unit. The small space heater is ideal for this purpose. By using it as a warm air furnace, by the addition of a jacket, with either forced or gravity circulation, a very satisfactory heating unit can be designed which has the advantage of very low initial cost and what is even more important, very low fuel cost. In some of these low-cost homes a utility room near the center of the house is used. By utilizing some of the radiant heat from the heater itself, and by jacketing a portion of it, a good uniform distribution of heat throughout a small area can be accomplished.

Continuous research is going on at an accelerated pace at many points in the country, much of it devoted to improving space heater equipment. Such organizations as Battelle Institute, the Anthracite Institute, and numerous private and state universities are devoting considerable portions of their appropriations to the further study of the space heater.

The stove manufacturers have now set up a committee to formulate standards of performance for coal heaters. Such standards have been in effect for years for oil and gas equipment, and notable work has been done by the American Gas Association and by the Petroleum Institute. This question of testing and approving equipment in the oil and gas industries has been one of the reasons for their progress, by eliminating such equipment from the market as is injurious to the general welfare of the industry.

Some very fine work has been done in the coal trade by the Anthracite Institute in the matter of testing and approving equipment. It is understood that the program now under way under the auspices of the stove manufacturers and Battelle Institute has the same objective in view, to the end that the bituminous coal industry may have equipment of proven merit to offer to the public.

Since nearly half of the homes in the United States are heated with portable heaters of some type, it is truly a national problem and one which deserves the best attention that can be given it. When one considers that the principal goal of most of us is the acquisition of food and shelter, and that shelter is essential only to protect us from the elements, the most important one of which is cold, this problem of supplying adequate, trouble-free heat for half the population is certainly one that merits the deepest study, not only by the public at large, but particularly by the coal industry, which has such a vital stake in this whole shelter problem.

IV. NEW DEVELOPMENTS IN THE FIELD OF COAL PREPARATION

H. P. Nicholson*

In this paper on recent developments in coal preparation, I am not going to dwell at any length on any individual technological developments during the past year or two, or in progress at the present time, but instead I am going to touch upon the major features of the problem of coal preparation and the economic considerations that affect them now or will affect them in the future. I am just going to touch upon a few of the important features that may be of interest to this group.

There has been a gradual improvement in the art and science of coal preparation during recent years. The development of the art and science of coal cleaning has coincided with the gradual change in emphasis from that of a partial sales argument to that of an honest engineering desire to produce a better and more uniform product to meet competition in a higher competitive fuel market. The trend in thought within the industry has been toward making improvement in cleaning operations (1) to produce a uniform product, (2) to produce the best fuel possible in consideration of the raw material involved, (3) to produce a fuel that satisfies the trade to which this coal is sold, and (4) to reduce the amount of losses in the coal cleaning process. Coal preparation plants now represent the application of scientific processes of producing better fuel.

Coal as mined from the ground is a natural raw material, in various degrees of purity, and seldom able, under present standards, to meet specifications without cleaning or other forms of preparation. The manner in which each particular coal should be prepared is a problem for the preparation engineer and the management of the coal company.

The coal consuming public is gradually becoming conscious of the desire on the part of coal producers to produce a quality fuel. Also, there is decreased tendency for some coal sales organizations to capitalize on certain phrases regarding their manner of cleaning to insinuate that their method of cleaning is superior to that used by their competitor.

A few years ago, it was not the policy of the management of coal mining companies to release technical data regarding washing plant

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operations because of the fear that such data might be used in an altogether misleading manner by their competitors. I am very glad to state that coal salesmen are now more appreciative of the engineering problem related to coal cleaning and preparation, and realize that technical data of plant operation, while of particular interest to coal preparation engineers and management, neither indicate nor are a measure of the quality of the product.

The coal consuming public is gradually adopting the same attitude toward well-prepared and trade-marked coal as toward other natural resources such as iron, lead, zinc, copper, etc. The consumer who buys metallic lead, zinc, copper, or iron is not particularly concerned with the richness of the ores of those metals, nor in the concentrating or washing processes required to remove the impurities from those ores, nor in the smelting processes to produce metal from those ores. The buyer is only interested in the purity of the finished metal with which he has to work. By the same token, the consumer of coal need not be concerned with the fact that in one plant the coal may be separated from the accompanying refuse at the equivalent of 1.40 or 1.45 specific gravity, while in another plant the coal may be cleaned at 1.50 to 1.60 specific gravity. It is entirely conceivable that the finished product at one particular plant cleaning coal at 1.45 specific gravity may have a higher ash content than the washed coal produced at another plant operating on a different coal and washing at 1.60 specific gravity. If the ash content, moisture, B.t.u., fusion point of the ash, and uniformity are the principal attributes that determine whether or not one coal is more desirable than another, then these attributes of the finished product are the facts to be considered, not the question of whether the coal was cleaned by wet or dry method, whether the separation between coal and refuse was made at 1.45 or 1.60 specific gravity, or other technical phases of internal plant control.

The processes in common use for the separation of coal from its impurities utilize the difference in the specific gravity of the coal from that of the refuse. This simple process is complicated by the fact that coal and its impurities are interlaminated to some extent, and that, in the natural breakage of the coal at the working face in the mine, lumps or pieces of coal are produced that may by accident be clean coal, others that are mostly clean coal but have minor bands of high ash impurities, others that are principally high ash lamina but with some good coal attached, and also some pieces that are entirely high ash material or clean refuse. Other clean refuse may be rock from the roof or clay from the floor. To the cleaning process is given the task

of separating the clean refuse and as much of the intermediate gravity or middling as may be necessary to produce a satisfactory marketable product.

Due to the banded nature of Illinois coal in particular, and most coals in general, and the possibility that larger sizes are more apt to have high ash laminae enclosed within them, it is frequently necessary to conduct the cleaning process at a lower specific gravity in order to produce an ash content in the larger sizes comparable to the ash content in the smaller sizes. When such a separation is made at 1.40 or 1.45 specific gravity a considerable quantity of middling, ranging in specific gravity from 1.40 to 1.60 will be produced that will be composed of alternate bands of clean coal and higher ash impurities. The discarding of such material as refuse is an economic waste, for from such material much clean and salable coal may be released by crushing and recovered by rewashing. The washing of the entire output of a mine at the same specific gravity either results in a high ash content in the washed larger sizes, if the washing gravity is high, or a great loss of coal in the refuse from the larger sizes if the washing gravity is sufficiently low to produce a satisfactory washed lump. The trend during recent years is toward the recognition of the necessity of washing the various sizes at different gravities to produce comparable ash contents in the various sizes, the middlings produced from each larger size being crushed and returned to be washed with the smaller sizes.

Such a plan is only possible with coal-washing machines that produce two types of refuse in addition to a clean coal product, a clean primary refuse, and a middling or secondary refuse, the secondary or lower gravity refuse being recrushed to liberate the clean coal. This gradually increasing practice of crushing the middling from each individual washing unit permits the production of a coal of low ash content and at the same time reduces the loss of coal in the refuse in so doing. With a decreasing market for the larger sizes and an increasing market for stoker sizes, the crushing of intermediate gravity material does not represent wasted energy, for in all probability the larger sizes would have to be crushed to meet the demands for stoker fuel.

The next phase in coal preparation is the dewatering of the washed product. The dewatering of coal may be divided into two classes, primary dewatering and secondary dewatering. Primary dewatering of coal may be accomplished by gravitation settling of the coal in a sludge tank, by the gravitational shedding of the water by the passage of the coal over a screen, or by the centrifugal removal of water from the surface of the coal in centrifugal dryers. While these devices remove a relatively large amount of entrapped water and possibly some of the surface moisture, the ultimate removal of the surface moisture can only be accomplished by heat drying. It is observed that there is a decided trend in recent years toward the heat drying of a larger percentage of tonnage of washed coal as such a practice is the best answer to the problem of freezing in transit, avoidance of freight charges on moisture in coal, and adjustments for moisture in sales agreements.

The problem of reclaiming as much of the clean coal in washing plant sludges, and of fine coal from the dedusting plant, as possible is receiving some attention, but not nearly as much as it deserves. The problem of cleaning and marketing sludge and fine coal is increasing in importance and will continue to do so as the tonnage of middlings crushed to liberate clean coal, and the percentage of lump crushed to stoker size to meet increased demand for that size, increase.

The problem of sludge recovery, aside from the fact that it is highly desirable from the point of view of conservation, must be solved on its economic considerations. I am not going to state that every ton reclaimed will add that much to the gross revenue of the industry, because, all things being equal, every ton of coal reclaimed from the sludge and sold in the same market will displace an equal quantity, or nearly so, of larger size coal. No one can get very far with an argument that a coal producer should spend money to recover fine coal from washing plant sludge that he may sell it at a low price in competition with his own coal of a larger size for which he is getting more money. If he can sell the fine coal to a consumer who has been purchasing coal produced by another company then all is fine and good, but if all companies were to do the same thing, then the total combined tonnage sold would be just the same and sales realization less. If sludge is to be recovered and the gross revenue of the industry increased, then the answer must lie in the proper preparation of that product so as to command the highest unit price and in selling it to a trade in an area in which it is not in competition with the remaining tonnage. Such markets may exist, as that for pulverized fuel to displace gas, or for coke and low volatile briquettes to displace low volatile eastern coal.

The coal sludge from most coal-cleaning plants contains too much ash-bearing material to be marketed without further cleaning. Possibilities of further cleaning may be in tabling, differential classification or settling, and froth flotation. The cleaning of fine coal on concentrating tables is not new, but has been used only to a limited extent because of the plant investment required and the limited capacity of individual machines. Differential classification or settling is much newer, having been tried recently in the midwest. In this system only the particles that settle near the entrance end of a sludge tank are reclaimed. By the use of more than one cross conveyor in the sludge tank various percentages of settled sludge may be recovered and remixed with other sizes. Little or no cleaning of the product takes place in such reclaiming, however, and the system can be practiced only when the sludge is relatively clean, or the product is not in competition in a quality market.

The froth flotation process is ideally suited for the recovery of clean coal from washery refuse. Fortunately, the largest size of coal particles that can attach themselves firmly enough to an air bubble to rise to the top of the mixture of water and solids corresponds with the usual maximum size of coal found in washing sludge. The adaptation of froth flotation to the recovery of coal is not new, either in this country or abroad. The commercial cleaning of coal by this method was first applied in Europe, principally in Belgium, Germany, and England, twenty to twenty-five years ago. At the present time it is required by law in Holland that the coal in all washing plant sludges must be recovered by flotation. In this country one or two plants have been constructed in Pennsylvania to recover bituminous coal from washing plant sludge, and a plant in eastern Pennsylvania to recover anthracite from river silt.

Bulk flotation of the coal in sludge, vitrain, clarain, and fusain, can be accomplished easily as coal is one of the substances floated by the froth flotation process. A higher objective, however, is the selective flotation of the individual banded ingredients producing products that are predominately fusain, clarain, and vitrain, respectively. When this has been accomplished new coal products will have been obtained that may have special uses. Research work is now in progress in the Department of Mining and Metallurgical Engineering on that problem.

In view of the smoke ordinance of the City of St. Louis prohibiting the entrance into the city of high volatile coal for use in hand-fired furnaces and stoves, it seems proper that interest and serious attention be given to the production of a low volatile fuel from Illinois coal. This devolatilization may be conducted in such a manner as to make the resultant product self agglutinating, and in the form of a semi-coke or coke. An alternative treatment may be in the nature of partial devolatilization and briquetting. Two plants of the former type, that is, coking, are now in operation in southern Illinois and producing coke for domestic as well as for some industrial uses. A plant for producing a lower volatile fuel by partial devolatilization followed by briquetting has recently been constructed and placed in operation in southern Illinois. All three of these plants are solving two problems in the same operation—namely, first, the utilization of fine coal that would be either wasted or sold at a price less than the cost of production, and second, the production of a high quality fuel to sell in the upper price brackets and in a market not competitive with the regular tonnage.

The question of the proper size of coal to be used in domestic stokers is one of great economic importance to the industry. Various tests have been conducted at various research institutions on the proper size of coal to use in domestic stokers. To the coal producer the demand for certain sizes is about like the demand of a customer in a meat market for a center slice of ham at the same price as asked for the whole ham.

The maximum and minimum size of coal to be included in stoker coal is a three-cornered argument, between the consumer, the sales department who wishes to please the consumer, and the preparation engineer and management who are interested in obtaining maximum total revenue for the output of the preparation plant. The position of the coal producer is that if the minimum size is placed at ½-mm. or still lower at 48 mesh, the quantity of sludge and dust that must be discarded as unsalable, while considerable, is not of disastrous proportions. If the minimum size is placed at 10 mesh or higher, up to ⅛-inch, the quantity of under size that is unsalable is of disastrous proportions. If the minimum size is boosted up to ¼- or 5/16-inch, the ¼- or 5/16-inch x 0 is marketable to a fair degree, and some revenue can be obtained.

The maximum size is important from the point of view of additional crushing and the resulting additional percentage of sub-sized material. The producer is faced with the dilemma of making the stoker size 1-inch or ¾-inch by ¼-inch, selling the minus ¼-inch coal as carbon, or producing a stoker coal with a ½-mm. bottom size. While some sales are no doubt lost by rather arbitrarily establishing a size for stoker coal on an economic or total sales return basis, yet until coal can be manufactured in any size we wish, like lead pellets for shotgun ammunition, the minimum size to be included in stoker coal is going to continue to be a subject of discussion between the consumer, the salesman, the stoker man, and the coal producer.

V. NEW DEVELOPMENTS IN AIR CLEANING OF COAL

Wm. C. McCulloch*

Pneumatic cleaning of coal has been of commercial importance since the first air tables were installed about twenty years ago. The tables used at that time originated from modifications of mineral separation processes which in turn had been developed for use in arid regions where water was not available as a concentrating medium. This factor presumably has not influenced the choice of coal cleaning equipment, although from recent reports of water shortages in several southern Illinois towns because of the prolonged drouth, it easily becomes of major importance.

Assuming an adequate water supply, the choice of pneumatic equipment for coal cleaning becomes an economic problem based on coal buyer's demands for dry coal. These demands, which are reflected in the installation of heat dryers as practically standard equipment in the majority of new washeries in this area, are based on such factors as frozen coal shipments, difficulty of handling wet coal through feeders and stokers of modern design, higher delivered B.t.u. values, and the greater amenability of dry coal to dust treatment.

It is not my desire to enter into any controversy over the relative merits of wet washing or dry cleaning of coal. Each has a specific application based on the washability characteristics of any individual coal, and it is my observation that many of the difficulties which beset early installations of dry cleaning plants have been surmounted, and satisfactory operations may now be obtained. I am reminded of such a controversy in a technical session a number of years ago in which the last comment to relieve the tension was that when you use water washeries the fish can't swim and when you use air cleaners the birds can't fly.

More recent technical developments have improved that condition, and although I have seen bluegills thriving in the sludge pond of a large washery, there is no necessity for letting black water run down the creek. Neither is there any necessity for dust to escape in the atmosphere if it is desired to retain it.

Similarly, technical men are familiar with those conditions which make it impractical to consider air cleaning in specific instances. If the coal is wet it does not necessarily preclude drying first and air

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cleaning afterwards. But if the coal is muddy and needs a water wash to improve the appearance, then wet washing is desirable.

Relative tonnages must be considered, and although in general there is no definite top size that may be cleaned by air, there are very few mines that produce enough of the larger nut sizes to make feasible the use of air cleaning equipment.

A study of the air cleaning installations of recent years indicates the trend toward combination plants with air cleaning on the sizes below ⅜ inch, or less generally ¾ inch, and wet washing on the larger sizes. The recent survey by "Mechanization" shows a yearly increase in air cleaning capacity installed and, although the rise is not as spectacular as the increases in other equipment, when one considers the fact that these air cleaning installations are restricted to the smaller sizes of coal, in most instances ⅜-inch or smaller, and that the washeries handle the sizes up to 6 or 8 inches, the comparison is remarkable. There is no question that the installed capacities of equipment for cleaning fine sizes shows a preponderance of air units.

I wish to make clear in my discussion of air cleaning units the difference between mere dedusting and the removal of ash or sulphur forming impurities. Quite obviously air-cleaning units that accomplish beneficiation of coal by removal of heavy impurities may accomplish the dual purpose of dedusting but the converse is not true. Removal of the extreme fines, particularly the —20-mesh material, by simple screening or air elutriation, does not improve the quality of the oversize. In the machines described below the dual purpose is attained.

Pneumatic machines fall generally into three classifications. There are the air-flow or launder type, the air-sand type, and the reciprocating table type. It is not necessary to follow the evolution of each of these types through the early models and the descriptions apply to the more recently installed machines.

The Stump Air-Flow coal cleaner is a device in which the basic principle of aerodynamics is utilized to the utmost to secure the maximum cleaning effect. The main structure of the Air-Flow is stationary. The only motion necessary for cleaning coal is provided by the pulsating air current, the moving distributing plate and the valve levers. The deck surface of perforated metal is smooth and does not impede the forward movement of the stratified material. Within the cleaner the air is distributed by means of a marble resistance pack augmented by simple adjustable valves which control the distribution to the deck areas. The pulsating air current in the plenum chamber is produced by a rotating shutter in the inlet and provides a more effective separating medium than a continuous air stream. The distributing plate which reciprocates in the bed of coal effectively breaks up channeling of the air stream and facilitates the progress of the coal down the deck which is set at a fixed slope.

After the coal and refuse are stratified on the deck, the refuse is withdrawn by means of oscillating plunger valves set at the bottom of the wells which receive the refuse. These valves are actuated by connecting rods which permit adjustment from the maximum setting to zero. In the most recent design, the Air-Flow cleaner has multiple refuse draws which permit removal of impurities over widely varying percentages. Middlings may be obtained from the final refuse draw and recirculated if desired. The clean coal flows over the end of the deck. Wire glass windows on the sides of the bed and curtained openings above permit continuous visual inspection. Recent installations show increased capacities because of greater width. The maximum standard size has a 72-inch wide deck.

The Air-Sand coal cleaner utilizes fine sand made fluid by means of air bubbled through the sand. The fluidity of the resulting medium spreads the coal in a thin layer so that rapid separation of coal and impurities takes place. In the removal of coal and impurities sand also flows from the machine. By the use of reciprocating screens and life wheels this sand is recovered and returned to the feed in closed circuit. Air distribution is controlled over the separating area by means of porous filtering blocks which are molded to form the bed of the separator box. When applied to fine coal ⅜-in. x 0 the same principle is utilized, except that in place of sand to form the fluid medium, the smaller sizes of coal form a substitute and are screened from the refuse to be returned to the circuit. These machines are available in compact self-contained units which may be installed in any available space of suitable dimensions.

The American pneumatic separator is based on the original reciprocating deck or table principle. Perforated deck covering with superimposed riffles permits stratification of coal and refuse, with the air distributed from below by baffles in the plenum chamber. The refuse is retained in the space between the riffles and is propelled toward the end of the machine where it is blocked by a banking bar to produce further bedding before being discharged diagonally across the end of the deck. The clean coal flows transversely over the top of the riffles aided by a deck tilting adjustment and is discharged over the side. Middlings may be diverted and recirculated if desired.

All steel construction with anti-friction toggles, deck supports, and eccentrics, combined with balanced deck operation, assure minimum vibration and power consumption. Variable speed drive and two-way deck adjustment provide flexibility to compensate for variations in feed rate and washability characteristics.

Comparative operating data are not available for publication but the following generalizations may be assumed as applicable to all pneumatic processes of cleaning coal. The visible moisture should not exceed 4 per cent of the feed. The exact allowable moisture is difficult to predict because of variable characteristics of the coal and its impurities, and the fact that there is no definite method of determining what the visible or so-called surface moisture may be. In pneumatic processes it is evident that moisture reduction is obtained as the coal passes over the cleaning unit. It would be quite feasible to use preheated air to accomplish this drying to a much greater degree and in high rank coal to remove some of the inherent moisture.

The dust may be recovered with the coal or wasted with the refuse, depending on the market requirements. In either instance the equipment to remove it from the air is the same. This equipment for maximum efficiency consists of cyclone and cloth bag collectors.

The top size of coal to be cleaned is dependent on relative cost when compared to wet washing and is not governed by any definite dimension at which air cleaning does not function. It is quite feasible to make the sizes cleaned conform to the shipping sizes with particular reference to the Illinois sizing schedule.

I repeat my earlier comments with the statement that the choice of pneumatic equipment for coal cleaning becomes an economic problem based on the coal buyer's demand for dry coal. To this may be added the growing market demand for dustless coal, and I know of one washery where the washed coal is heat dried and then passed over dedusting screens. This triple operation of cleaning, drying, and dedusting, is accomplished in one pass over a pneumatic cleaning unit.

VI. ASH CONTROL IN COAL WASHING PLANTS

PAUL W. F. J. MORAN*

In the modern march of progress the art of coal preparation is becoming more and more exacting. Uniformity is the watchword for the coal preparation engineer. In order to achieve the Utopia we are all looking for in uniformity of prepared coal, testing methods must be devised to maintain high quality and absence of complaints. The methods which are or must be adopted will vary widely with the different types of coals and different types of cleaning equipment.

Experience with the American Society of Testing Materials and other slow, time-consuming methods caused an investigation of possible rapid, time-saving methods for control of the washery to be undertaken. After considerable investigative work, the rapid "Control Ash" method described herein was developed and adopted as standard practice in many laboratories throughout the country. There are three methods of washery control: visual, sink-and-float, and ash regulation.

The visual method may be utilized very easily for some types of coals where there is an accumulation of very low specific gravity material at the required separation point. In this case, the separating gravity is very near the dividing line between clean coal and refuse material, or a so-called black and white separation. This method is of little value where the separating problem is difficult.

The sink-and-float method is much more tedious, but is essential for some elements of washery control. However, the customer is not interested in the percentage of sink material in the coal he buys, but is more interested in the ash content. By means of graphs worked out for each individual coal the sink material percentages may be converted to ash content, but a wide variation in results is usually obtained due to the different character of materials which are usually present in the sinks. There are many coals whose float ash vary several per cent, which are certainly cases that could not be figured on a sink-and-float basis. Thus the sink-and-float method is slow, tedious, and usually does not give an accurate evaluation for the ash. Regardless of the control methods employed, some sink-and-float work is generally necessary. As all coal cleaning devices depend on the differential in specific gravity between the coal and the impurities,

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some sink-and-float work must be done to establish efficient operation of coal cleaning units.

Development of a rapid ash method of regulation was deemed desirable in order that information valuable to both sales and operating departments could be had with sufficient accuracy and speed for efficient control. With the increasing size of preparation plants and rising tonnages passing through the existing plants high speed methods of control are imperative. Methods are now in use which enable the cleaning plant operators to have control ash results flashed to them about twenty minutes after the collection of samples.

As speed is essential, a routine must be worked out to utilize all mechanical means possible to limit the time necessary for each operation. Thus the laboratory must be located as near to the point of sample collection as practical. For most plants this would be near the plant and on the down track side. The more highly mechanized the routine the fewer men required to make it function.

There are perhaps as many schemes or routines of sampling and control in use as there are companies or perhaps mines. These schemes vary from taking daily composite samples to collecting samples on every car of washed or cleaned coal loaded. Several mines have adopted hourly or half-hourly sampling periods. There is a wide variety of routines followed after the sample has been collected, from the modified rapid ash method to a complete proximate analysis according to methods of the American Society of Testing Materials.

The customer is interested not only in the ash content of the coal he burns or buys, but even more in the uniformity of the ash content.

Practically every type of coal cleaning device operates in some sort of a cycle. By this cycle I mean the complete course of operations pertaining to the removal of the rejects, and returning to the original state. There are some cleaning devices which utilize a continuous draw of reject material, and there are others which have an intermittent draw. There are still other types of cleaning devices which have an intermittent draw, but are capable of elimination at an infinite number of speeds. In any case the cycle of operation must be reduced to a minimum time interval to produce a uniform product. The cycle of operation of the cleaning unit, or in some cases the entire preparation plant, is very important in determining the sample procedure and the size of sample that must be collected to give the proper representation. A large number of small samples will give a much better picture of the uniformity of the product although it may not be so rosy. The figures from the analysis of daily composite samples will

in most cases fall within a narrow range. One would think that this would represent uniformity, and it does represent uniformity in some cases. After all a composite is only an average of the analysis of various sample increments which went to make up the composite sample. The analysis of the various increments might have had a wide variation, especially in the case of a cleaning unit with an inherently long cycle of operation.

In order to achieve the utmost in uniformity of ash one should collect a large number of small samples for analysis. I favor an analysis on every car with the analysis run as rapidly as possible, still maintaining sufficient accuracy to give useful information for control. To be useful for control, time is the essence, therefore high speed ash analysis is essential. With all of these factors in mind I am going to outline a procedure for making a high speed ash analysis.

The sample, as collected, is brought to the laboratory, and without previous quartering or drying, is crushed through a 12 in. x 12 in. ring crusher to probably 10 mesh. To expedite matters, a riffle with a hopper can be built into the wall of the grinding room, near the crusher to be used for sample reduction. This will help as a time-saver, since the discard portions of the sample are delivered directly to a bin outside the laboratory. The final reduced portion of the sample is retained and placed in a shallow pan, in a thin layer. The pan containing the sample is placed in a drying oven at a temperature of about 400 deg. F. Within a period of about four minutes the moisture may be reduced to about two or three per cent, more or less uniform, so that the control ash which is later run may be converted to an approximate dry basis immediately. Upon removal from the oven, the sample is pulverized to 60 mesh through a rotary disc pulverizer. The pulverized sample is riffled to about two ounces and placed in a stoppered bottle. The sample is then passed to the analytical room of the laboratory.

The analytical laboratory is fully equipped for making complete analysis on fuels and water.

The control ash corner of the laboratory is shown in Fig. 1. The analytical balance is a precision chainomatic instrument with a gram rider on the beam, and gives fast operation. For our routine we use a tared weighing pan to weigh both the sample of coal and the ash after reduction. It is, therefore, not necessary to use outside weights except the tare weight which remains on the balance. Using this procedure, the ash percentage is read directly from the weight of the ash product, simply by mentally multiplying the milligram weight of the

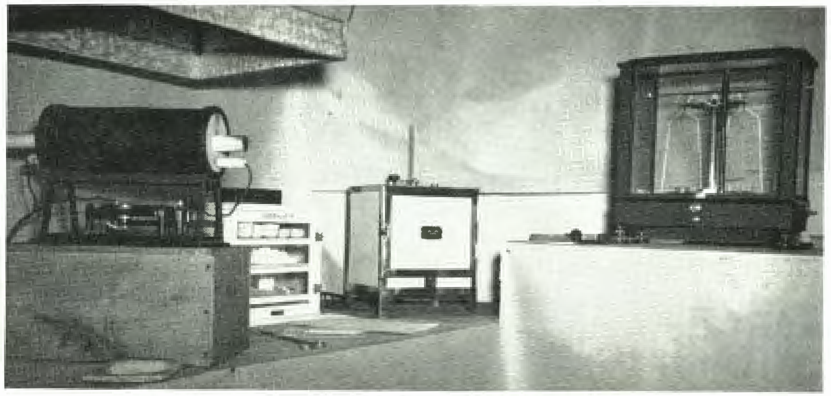

FIG. 1

ash by ten, provided that an original sample weight of one gram was used, and no other calculation is necessary.

The one gram sample is placed in a combustion boat which in turn is placed in a single-unit Hoskins type FD 303 electric combustion tube-furnace complete with a rheostat to regulate the temperature, and fitted with a reduced end combustion tube. The combustion tube-furnace set-up is shown in Fig. 2. The combustion tube is introduced into the furnace so that the large open end of the tube just protrudes about the length of one of the combustion boats beyond the end of the furnace proper. By allowing the combustion tube to extend through the furnace, a hearth is present within which the loaded boat is allowed to warm up at a reduced temperature for the evolution of the volatile matter without violence, which might cause mechanical losses from the sample. The boat is advanced into the high temperature zone of the furnace for complete combustion. Rapid burning is accomplished through the use of added oxygen delivered to the combustion tube.

Oxygen, from a cylinder fitted with a pressure-reducing gauge, flows through a short piece of rubber tubing to a bubble bottle, and thence through another piece of rubber tubing connected to the reduced end of the combustion tube. The bubble bottle is fitted with a two-hole rubber stopper and glass tubing connections. The rate of flow may be observed by the bubbling of the oxygen through the water in the bottle. The bubble bottle also serves as a flash protector.

Complete oxidation of the coal to ash is accomplished in five minutes exposure in the tube, by proper control of the temperature and

FIG. 2

flow of oxygen. Upon the complete ashing of the sample the boat is withdrawn from the furnace and cooled for weighing. The resulting figure is designated as "Control Ash" and is flashed to the operator in charge of the cleaning plant. The information can be transmitted by means of an electric "score" board located at a convenient point in the preparation plant, and operated by switches mounted within reach of the chemist from the balance table. Thus the chemist can flash the control ash as soon as the last swing of the balance has been made.

Experience has taught that the control ash figure may be converted to moisture-free ash by a calculation based on a 2½-per cent moisture allowance. While this is a reliable figure, the moisture-free ash figure may be calculated and available approximately an hour after the ash analysis is made. As soon as the ash sample has been weighed, a moisture sample is weighed and placed in the moisture oven. A moisture figure is available in about an hour, which makes it possible to convert to the moisture-free basis in a very short time.

Results are close to the permissible tolerances allowed by the American Society of Testing Materials. In Table 1 you will see the results of the various analysis on samples taken from ten different cars of screenings loaded in sequence. The table shows the control ash, the moisture remaining in the pulp from which the control ash was determined, the dry ash from calculation using the foregoing

TABLE 1

Sample	Control Ash per cent	Moisture in Control Sample per cent	Dry Ash from Control Method per cent	Dry Ash A.S.T.M. Muffle per cent	Dry Ash Foreign Laboratory per cent
1	9.55	2.65	9.81	9.66	9.59
2	9.82	2.13	10.03	9.71	9.77
3	9.39	3.11	9.69	9.75	9.62
4	9.42	2.76	9.69	9.74	9.82
5	9.61	2.65	9.87	9.80	9.69
6	9.26	2.80	9.53	9.62	9.53
7	9.44	2.63	9.69	9.53	9.65
8	9.35	2.71	9.61	9.48	9.62
9	9.63	2.44	9.87	9.91	9.85
10	9.85	1.95	10.05	9.92	9.91

moisture and the control ash figures, the actual dry ash run on a separate portion of the head sample, and the results of dry ash run by a foreign laboratory.

VII. CARBONIZATION OF COAL BY THE DISCO PROCESS

C. E. LESHER*

Carbonization of coal by the Disco process gives a smokeless solid fuel. The product is a semi-coke, or as it is more commonly termed, a low-temperature coke. Low-temperature carbonization is the partial distillation of coal. High-temperature carbonization is complete distillation of coal. The difference in the product is in the volatile content. High-temperature carbonization gives a coke with volatile matter of two per cent or less. The percentage of volatile matter in low-temperature coke may range from 14 or less to as high as 19, depending on the coal used and the process employed. In between lies medium-temperature coke, with volatile content ranging from three or four per cent to ten per cent.

Semi-cokes with volatile matter or less than twenty per cent are smokeless, and it is because of this important characteristic that there is so much current interest in Disco. Other characteristics of Disco are its ease of ignition, firm structure, and density. It is regularly stored in piles twenty to more than thirty feet high with no more size degradation than high-volatile lump coals. It is a highly desirable domestic heating fuel, and is used over a wide area in homes for central heating furnaces, stoves, ranges, hot water heaters, and fireplaces. The process of manufacture gives a product that is self-trademarking, because of the ball-shaped pieces. It is marketed in two sizes, 1 in. x 6 in. and 1 in. x 2 in.

The process is indeed simple. The continuous heating and carbonizing of coal in an inclined revolving retort to form low-temperature coke in rounded, homogeneous, ball-shaped pieces is the essence of the process.

Preheated finely divided coal and breeze are conveyed by the revolving action of the inclined retort toward the discharge end, the temperature of the coal mixture increasing until it becomes soft or plastic. The hot, dry, fine coal and breeze do not stick to the steel but flow as freely as a fluid. At a temperature about 700 deg. F. the coal softens and gives off hydrocarbon vapors, and distillation, as generally understood, has begun.

As the coal softens it becomes sticky. The whole mass does not

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melt into a fluid state, but some constituents of the coal soften, wet the surfaces of adjacent or inert particles and bind the whole into a loosely coherent mass. In this condition its coefficient of friction on steel is greatly increased. Instead of a thin layer, loosely flowing, there is a thickening of the bed, because the increase in friction not only retards its flow down the retort but increases the length of climb up the arc of the revolving shell. The charge has changed from dry to wet and is now in the plastic stage. This transition takes place within a short interval.

Revolving action of the retort raises the mass and as it falls over it is kneaded and disintegrated into smaller masses, quite irregular in shape and size. The loosely coherent mass literally falls apart. The segregation into small masses that later become hardened as coke balls is not dependent on "snowballing" action—that is, the larger masses are not the result of small pieces rolling down a surface of material and increasing in size as a snowball gains in size as it rolls down a slope. The size of the masses that finally merge as coke balls is determined by the agglutinating property of the coal at the time it reaches its softening temperature in the retort.

Transition through the plastic stage is rapid, about 5 to 10 minutes, perhaps even less for some coals. The semi-fluid mixture is torn apart by the revolving action of the retort into soft masses that quickly attain sufficient consistency to be individual pieces that quickly become dry and solid, with roughly spherical shape.

Size and structure of the coke balls are the important objectives in control of the process. The desired size of product is a range between 1 and 8 inches. The structure should be dense, homogeneous, and resistant to shatter. Experience has shown that for any given coal:

(1) The "size" of the pieces that emerge as low-temperature coke balls is determined by the agglutinating property of the coal at the time it reaches its softening temperature in the retort.

(2) The "structure" of the low-temperature coke is determined: (a) by the character and proportion of inerts mixed with the coal and (b) by the rate and maximum temperature of heating and the effective control of the rates and temperatures in preplastic, plastic, and post-plastic ranges.

Bituminous coals with a certain minimum of coking power can be processed to Disco. That minimum can be expressed in terms of the agglutinating index as at about 3 (15 to 1 ratio). Coals that are so weakly coking must be processed by rapid heating to take advantage of all the plastic material in the charge. A strongly-coking coal, such as one with an agglutinating index of 7 or more, will not make satisfactory Disco unless the coking property is reduced either by preliminary oxidation or the admixture of inerts—as coke breeze.

Bituminous material with high agglutinating index, such as coal-tar pitch or a strongly coking coal, can be mixed with weakly coking coal or even inert material, to give a mixture that can be processed into coke balls. A highly coking coal can be made into the desired size and quality of coke balls by this process, without preliminary roasting, by blending with sufficient inert material.

Not only do coals from different fields have different plastic ranges and agglutinating values, but the normal commercial sizing of coal from any mine gives coals with varying plastic ranges. A plant designed to make low-temperature coke by this process from a highly coking coal would be different from a plant designed to treat a weakly coking coal.

There is a notable difference in coking property between —48-mesh, —10-mesh, and —$\frac{5}{16}$-in. coal from Franklin County, Illinois, coals, to be largely accounted for, of course, by the accumulation of inert fusain in the extreme fines.

The Disco plant of the Pittsburgh Coal Carbonization Company is a self-contained operating unit. The coal processed is —8-mesh or —$\frac{3}{8}$-in., having 37 per cent volatile matter and about 8.5 per cent ash. The products are low-temperature coke and tar which is collected and delivered to storage tanks. By-product coal gas is used raw for heating the roasters and carbonizers. All coke that passes through a 1-in. screen is crushed to —$\frac{1}{4}$ in. and recirculated in the carbonizers.

The process is continuous and the plant is operated 24 hours a day and seven days a week. Present practice is to shut down the plant twice a year for overhauling of conveying, screening, and handling equipment. Individual units may be taken off production at any time for cleaning scale from the retort. Raw coal handling is by belts and conveyors by which the feed is distributed to 24-hour storage bins over each of the three retorts. A disk feeder under each bin delivers a uniform supply of coal to the unit.

Heating is accomplished in a closed circuit with high-speed gas. In a refractory-lined furnace by-product gas in controlled amounts is burned and mixed with recirculated gas so as to maintain a temperature of about 1020 deg. in the mixture. The heating gas is forced through the annular space around the carbonizing retort at a speed of about 3500 feet per minute. Its temperature as it leaves the carbonizer is between 850 deg. and 900 deg. The roaster and storage conveyor are heated by the gas after it leaves the carbonizer. There is a drop in temperature of about 200 deg. in this part of the circuit, and the gas reaches the inlet of the recirculating fan at between 650 deg. and 700 deg. Between the fan outlet and the furnace the excess gas is vented. The products of combustion do not contact the coal in process.

The flow of coal is from the bin to the roaster. Here in thin layers on horizontal cast-iron hearths the coal is stirred and conveyed by rabbles for about two hours. Oxidation is controlled by the time and temperature of treatment and the quantity of air admitted to the roaster. Roasting the coal to oxidize it partially is necessary for highly-coking coals, to reduce the agglutinating property before carbonizing in the revolving retort.

Coal from the roaster, at about 600 deg., is conveyed to the storage conveyor which holds a supply for the carbonizer sufficient for from one to three hours. The storage conveyor serves to smooth out changes in coal quality as well as to equalize irregularities in the flow from the roaster. A feeder measures a constant volume from the storage for the feed to the carbonizer.

The carbonizers are inclined rotating steel cylinders. Surrounding the rotary cylinder is a stationary shell insulated on the outside. Heating gases pass through the annular space between the two shells at high speed and heat the revolving element. Into the upper end of the revolving retort coal from the storage conveyor is carried by a screw and by-product gas is withdrawn by an exhauster. The lower end of the retort is open to the atmosphere and the hot low-temperature coke is discharged in a continuous stream into a gathering conveyor.

Coke that will pass a two-inch screen is water-quenched, but it is necessary to cool the larger low-temperature coke balls in air, as quenching with water causes shrinkage cracks that destroy the structure of the balls. The cooling wharf is made up of slotted grates in step formation, the whole inclined at an angle of 18 deg. Trippers in an endless chain raise and lower each grate in turn, imparting a wave-like motion to the bed of coke, and moving it slowly down the wharf. After 2½ hours of air-cooling, the temperature of the larger (6-in.) balls has been reduced to less than 400 deg. At this temperature the coke can be screened and loaded into cars.

Breeze, the —1 in. undersize from production, is recirculated after it has been crushed to —¼ in.

By-product gas is withdrawn from the upper end of the carbonizers. In a stationary insulated chamber, dust is settled out. From this point the handling of gas follows regular practice. Tar is condensed by direct water sprays and an exhauster and small gas holder collect the raw gas and deliver it to the burners at each furnace.

In physical appearance Disco is dense grained and black. Its shape is characteristic of the process, irregularly rounded balls, or fragments of balls. The shatter index is above 70 per cent retained on a two-inch screen.

Agglutinating value of the —8-mesh coal is 11.5 (15:1). The apparent specific gravity of Disco is 0.856; true specific gravity, 1.456; percentage of porosity, 41.2. The weight per cubic foot of +1-in. size Disco is 33.2 pounds.

By-products from the low-temperature carbonization of coal vary in kind and quantity, depending upon the type of carbonization process used and the coal carbonized. The by-product yields obtained at Champion will not necessarily hold true for other coals, and will vary according to whether the coal requires roasting or a rapid rate of heating to make a satisfactory coke. Roasting and slow rates of heating below the melting point of coal lower the yield of tar and give a somewhat higher yield of coke.

In general, the products obtained by the Disco process in addition to coke are tar, light oil, liquor (aqueous liquid), and noncondensable gas. Thus far tar and coke are the only products sold commercially.

Depending on the coal used, the yield of coke ranges from 63 to 75 per cent, dry basis. Tar per ton of coal is from 15 to 30 gallons. The heat available in the gas ranges from 400 to 1000 B.t.u. per pound of coal carbonized.

A characteristic peculiar to virtually all low-temperature carbonization processes, including the Disco process, is the absence of naphthalene in both raw gas and tar. A further peculiarity is that the aqueous liquor contains no ammonia in commercial quantities, and is acidic rather than alkaline.

The most important by-product for commercial purposes is the tar. The tar produced at the Champion plant is a mixture of primary tar and decomposition products formed in the course of pyrogenic condensation and oxidation in the process. The pretreatment of the coals in the roasting stage affects the kind of tar produced. Like the other by-products the chemical content and physical properties of the tar vary with the coal being treated. This tar is not orthodox low-temperature tar. Its specific gravity is high, 1.14 at 25 deg. C. It is rather viscous and not very fluid at room temperature. It is high in insoluble matter, with 18.5 per cent insoluble in CS_2. This is due, not to "free carbon" content, which is under 5 per cent, but to some flocculation of the tar in CS_2, and to dust that travels with the gas stream as it leaves the carbonizer.

In the operation of the tar stills at Champion approximately 50 per cent of the tar comes off as an oil distillate containing 39 per cent tar acids, of which the greater amount is high boiling.

The tar acids are the most valuable constituents of the tar, and as they represent at least one-fifth of the tar, are an important source of by-product income. The growing importance of plastics in industry point to an increasing market for this product, since the phenols and cresols are raw materials for plastics.

Summary

A plant for making Disco from bituminous coal consists of apparatus for drying and heating the coal, and controlling the coking property of the preheated material, rotating steel retorts for carbonizing to low-temperature coke balls, together with coal and coke handling equipment, and facilities for collecting and cooling tar and gas. Preheating of coal may be done in either rotating cylinders, externally heated, or on rabbled hearths. Rabbled hearths are used for preliminary oxidation or "roasting" of strongly-coking coals.

Carbonizing is done in rotating steel retorts heated both externally and internally. All of the apparatus is made of ordinary steel. Conveying and screening of solids and gas and tar collection are by standard methods.

The Disco process is adaptable to a wide range of coals, from which there is made smokeless solid fuel. The principal by-product is tar, which yields a high percentage of valuable tar acids and creosote distillates.

VIII. PRINCIPLES OF SMOKE FORMATION AND ELIMINATION

BERTRAND A. LANDRY*

From the point of view of smoke formation, all fuels can be divided into two groups: those that cannot be made to smoke, irrespective of how they are burned, and those that will smoke if improperly burned. Interestingly enough, all fuels found in nature, whether solid, liquid, or gaseous can be so burned as to produce smoke. This statement applies even to anthracite, although it is admitted that under any practical burning conditions this fuel produces almost no smoke. An example of a truly smokeless fuel is high-temperature coke, but this is a manufactured product. Natural gas and fuel oil, when burned with an improper mixture of air, will produce smoke in any amount. This property of natural gas is utilized industrially for the manufacture of carbon black. Any one who has seen a petroleum or fuel oil tank on fire will testify to the spectacular evolution of smoke which accompanies the burning. One useful application of smoke emission from fuel oil burners is found in naval warfare tactics with the laying of smoke screens.

Inquiry as to the nature of the smoke forming constituents of fuels indicates that they are largely the hydrocarbons—compounds of carbon and hydrogen—present in varying amount in all natural fuels. The variety of hydrocarbons existing in nature is almost endless, and fuels usually contain mixtures of many kinds which, if separated and observed at room temperature, would range all the way from light gases and liquids through to heavier liquids and solids such as waxes and tars.

Natural gas and fuel oil are almost entirely composed of mixtures of hydrocarbons, which happen to be gaseous in one case and liquid in the other. Coal, by comparison, contains much less hydrocarbons, but these tend to be of the solid kinds, and normally will separate out from the coal only when the temperature is raised sufficiently for them to melt or gasify.

Conditions for Smokeless Combustion

Irrespective of their form, hydrocarbons can be burned successfully without smoke only if both of two well known conditions are fulfilled. These are (1) that they will be admixed with sufficient air,

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and (2) that the temperature of the mixture will be such as to result in complete and maintained ignition.

These two conditions are fairly easily fulfilled when burning gas or oil if the burner construction provides for an intimate mixture of fuel and air, and if the flame does not impinge too soon on a cool surface. The problem of the burning of the hydrocarbons in coal can be solved by similar means if the coal is pulverized before burning. Hence, products of combustion from a well-regulated pulverized coal furnace will not contain smoke.

If the coal is burned in a bed, however, and if the nature of the bed or the method of firing are such that much smoke arises from the bed, then it is no longer a simple matter to burn the smoke completely. This is difficult because in the combustion space above the bed all four of the following conditions must be fulfilled simultaneously: (1) there must be enough air present, (2) this air must be suitably mixed with the gases, (3) the temperature must be high enough for complete ignition, (4) enough time must be available for combustion of the rapidly moving gases before cooling occurs. It is usually found that these conditions tend to be mutually opposed, in the sense that if one of them is provided for, some other is removed by the same process. Innumerable devices have been developed and sold to improve over-fire burning, in overfeed hand-fired furnaces for example, but, so far as the writer is aware, none has been completely successful as a smoke eliminator.

It would appear, therefore, that the better way to eliminate smoke from equipment burning smoky coal is to prevent the evolution of smoke from the bed itself. To understand better how this may be possible it is necessary to examine closely the nature of the various kinds of fuel beds and to analyze carefully the actions which characterize them.

Types of Fuel Beds

As pointed out by P. Nicholls in a publication entitled "Principles of Fuel Beds,"* there are three fundamental kinds of fuel beds: (1) the overfeed, (2) the pure underfeed, and (3) the cross feed. These terms are not entirely satisfactory, as the first two do not indicate by themselves the essential differences between the fuel beds concerned in that they refer only to the motion of the coal and not to that of the air for combustion. It should be clearly stated, also that actual fuel beds do not necessarily conform entirely to one and only

*P. Nicholls, "Principles of Fuel Beds," Transactions, Am. Inst. Min. and Met. Eng., Coal Division, 1936, pp. 183-197.

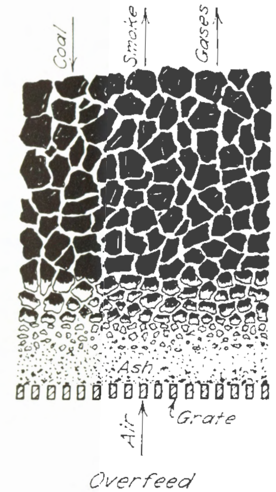


Fig. 1

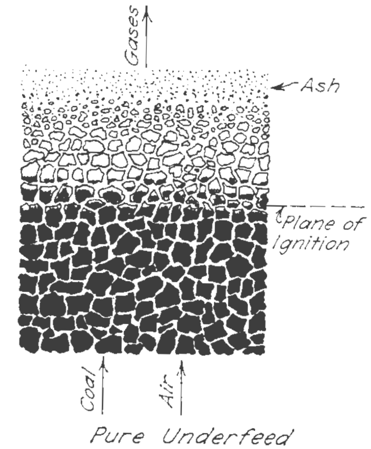


Fig. 2

one of these types. Notably with the unusual or special designs of hand-fired equipment that appear on the market from time to time and also with mechanical underfeed stokers, the resultant fuel bed may combine two or more of the elementary types. These limitations were, of course, recognized by Nicholls, and serve to emphasize the need for a logical approach in any study of fuel beds.

Overfeed Burning

Figure 1 is a representation of the ideal overfeed type of fuel bed. The coal is fed from above, either continuously or intermittently. The air enters from below and meets first a layer of ashes where it is preheated and then passes on to the hot zone of active combustion. As soon as this happens, the oxygen in the air begins to combine with the combustible carbon to form carbon dioxide, the corresponding heat of combustion being liberated. The oxygen is not all used up at once but is gradually scrubbed out or removed from the air and gases as they pass up through the bed. If the bed is thick enough, not only will all the oxygen be used up, but the carbon dioxide will combine with more carbon and carbon monoxide will be formed.

The thickness of bed which is required for these actions to take place completely depends on the kind of fuel which is used and, especially, on the size of the pieces in the successive layers. From the point of view of economy, it is of course most desirable that no carbon monoxide will be formed and that all the oxygen be used up. It is usually impossible, however, to fulfill both of these conditions and it is found that with almost no carbon monoxide there will be nevertheless some excess oxygen. This is about the most economically practical bed and, to achieve it, it is usually required that the bed be fairly thin, say eight to ten inches for a 2 x 3 in. coal; also, the bed must be clean and without blowholes.

To maintain such a bed when burning at somewhat near the rated output of the furnace requires almost constant attendance and frequent light firings. Under these conditions it is possible to hand fire a smoky coal, on an overfeed bed, with production of little smoke because the volatile, as it leaves the fresh coal, will find enough oxygen at a high enough temperature to be ignited and completely burned. Obviously, however, this economical and smokeless bed can only be maintained with a full-time, competent fireman or an equivalent mechanical means.

On the other hand, it must be equally obvious that with heavy firings of a smoky coal, an overfeed type of bed will produce smoke. Viewed simply, this is because the air for combustion and the coal itself move in opposite directions in the overfeed bed. When a thick layer of fresh coal is fired, the heat from the residual bed will distill the volatile hydrocarbons from the lower layers of coal; but this action, in all likelihood, will so cool any excess air from the bed that the ignition temperature may not be reached. At any rate, the mixture of hydrocarbons, oxygen, and other gases is further cooled as it continues its passage through the green coal, consequently, its constituents do not burn and the bed releases smoke.

To summarize: (1) an overfeed bed is one where the air through the bed and the coal in the bed move in opposite directions; (2) smoky coals can be burned smokelessly if the bed is maintained at the proper thickness and firings are light; (3) heavy firings will invariably result in smoke emission from the bed, and it is admitted that it is usually very difficult to burn this smoke once it has left the bed.

Pure Underfeed Burning

The pure underfeed bed is pictured in Fig. 2. Here it will be noticed that the principal difference from the overfeed bed is in the relative directions of motion of coal and air. Instead of a countercurrent flow, both coal and air move in the same direction in the pure underfeed fuel bed. The word underfeed is, of course, not comprehensive, as the picture could be turned upside down with the coal and

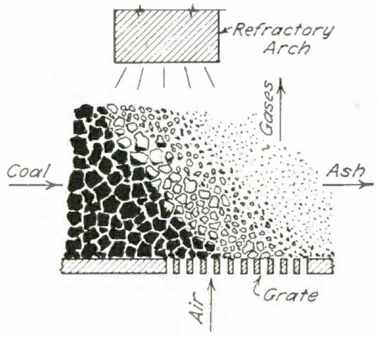
air both overfeed and nothing would be changed of the characteristics of the bed. Figure 2 shows that the coal and the air are both pictured as moving up; in this instance, the fire would be lighted from the top and after reaching equilibrium conditions the plane of ignition, that is, the plane where combustible and air begin to burn, would be at some distance below the top of the bed as shown. Equilibrium means, therefore, that the rate of advance of ignition is the same as the rate of burning and the bed maintains a constant thickness. It is, of course, assumed that fresh coal is being pushed up at the same rate and ashes removed from the top.

It has been observed that such a fuel bed will not smoke, even when burning the most smoky coals. The reason is obviously the fact that volatile being given off at the plane of ignition and above can immediately mix with air of high oxygen concentration and the mixture, moving as it does through zones of increasingly higher temperatures, is completely ignited and burned.

The application of this principle to the design of burning equipment would appear to be of promise for the elimination of smoke. Unfortunately, an equilibrium bed of the kind described can be maintained with most coals only with rates of burning of 20 to 40 pounds of coal per square foot per hour and this under constant operating conditions. This difficulty can be turned to advantage in industrial installations, but there seems to be little hope that it can be overcome in domestic heating. In addition, it appears that mechanical devices must be provided to move the coal and possibly the air.

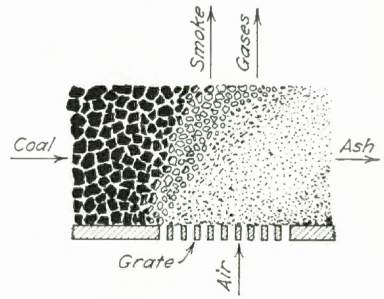
The small underfeed pot-type stoker operates partly on the pure underfeed principle, but the bed is not an equilibrium bed and some of the burning at the edge or over the edge of the retort is more properly a mixture of the various types of burning, including overfeed. Reasons for this choice of fuel bed conditions are directly found in the intermittent character of stoker operation, whereby the heat load is met by the respective durations of the off and on periods and, also, in the suitable disposition of the ash released from the coal. Because they do not operate entirely on the pure underfeed principle, underfeed stokers will produce some smoke at certain stages of their cycle of operation, but this smoke is usually far from being of such a density as to constitute a nuisance.

The possibility of turning the pure underfeed bed upside down cannot be overlooked. Arranged in this way it is possible to depart from the high rate of burning in the equilibrium bed by restricting the coal feed so that the plane of ignition is always at the top, coal being



Cross-feed—Ignition from Above

Fig. 3



Cross-feed—Ignition from Below

Fig. 4

fired only at the rate it is desired to burn it. This is sometimes called the down draft method of burning and will not produce smoke. There is real promise in a suitable design embodying this principle; but, for domestic equipment, there seems to be no simple way of feeding the coal without mechanical means. With a free-burning coal, that is, one which does not cake before coking, it appears possible to provide in a down draft heater for the firing of substantial amounts in intermittent hand firings. But this may not be possible with a caking coal because of the coke arching which would take place across the bed, requiring laborious attendance between firings.

Summarizing pure underfeed burning: (1) the air and coal move in the same direction, and for this reason no smoke will leave the bed once the underfeed conditions are established; (2) smokeless hand firing of non-caking coals appears to be a practical possibility with the down draft version of pure underfeed burning; (3) it is believed that strongly caking coals may be suited to down draft burning if some modification is introduced to prevent arching.

Cross-Feed Burning

Cross-feed beds are shown in Figs. 3 and 4. As the name implies, the characteristic principle of these beds is that the coal feed and the air feed travel in directions which are perpendicular to each other. The grates shown are not necessarily fixed, but may serve to move the coal. The best example of a fuel bed utilizing this principle is the chain-grate stoker, where the fuel moves on an endless chain until combustion is completed, the ashes being dumped at the end turn.

The plane of ignition, in a cross-feed bed, may be inclined as in Fig. 3, where it makes an angle greater than 90 degrees or as in Fig. 4, where the angle is less than 90 degrees. Evidently, the difference between these two beds is that, with a smoky coal, the bed of Fig. 3 will burn smokelessly and the bed of Fig. 4 will produce smoke. These two beds are comparable, respectively, with the pure underfeed and the overfeed; accordingly, if the volatile is mixed with air before passing through the hottest zone, smoke constituents will be consumed; but if the oxygen is used up first by passing through a hot zone, the volatile from the green coal above will go off as smoke.

With chain-grate stokers there is a fairly simple means of insuring that the ignition plane will be as in Fig. 3 for smokeless combustion. This consists in placing a refractory arch over the bed at the point where fresh coal enters the furnace. If furnace temperatures are high, the arch will be heated to the point where it will radiate heat to the top of the bed and ignite it in the desired manner. This action to be successful requires high furnace temperatures or a high rate of burning. Otherwise, the tendency may be for the ignition to proceed as in Fig. 4, the bed being smoky.

Cross-feed burning does not require that the fuel move horizontally as shown. The fuel can be considered to move up or down, the air moving at right angles, and the same principles will apply. From time to time there have appeared on the market heating stoves or domestic heaters in which some cross-feed burning of this kind undoubtedly takes place. Whether or not smokeless combustion follows must depend, in final analysis, on whether the plane of ignition is as in Fig. 3 or as in Fig. 4. And, in this connection, it must again be emphasized that to obtain the fuel bed condition of Fig. 3, a source of ignition situated opposite to the flow of air must be provided for. Because of this restriction it would appear that a serious difficulty exists with regards to operating such equipment smokelessly at low rates of burning.

Conclusion

In conclusion, the principles of smoke formation and elimination, insofar as they depend on fuel bed conditions, appear to be quite simple. Any industrial size, coal-burning furnace that is operated continuously at relatively high rates of burning should never produce smoke if well designed and attended. The small domestic heater or furnace remains, however, a contributor to the smoke problem of localities embarrassed in this way. The combination, in this type of equipment, of large intermittent firings, infrequent attendance and from medium to very low rates of burning seems to make it difficult to correct the situation basically by simple means.

It is believed, nevertheless, that ingenuity and invention, utilizing some of the principles explained, either singly or in combination, will succeed in producing effective and practical designs of smokeless heaters.

IX. NEW DEVELOPMENTS IN STOKER DESIGN*

Frank Hoke†

Developments and improvements in the stoker industry are influenced by many factors, the chief ones of which are:

(1) Keeping up or ahead of competition
(2) Demands from purchaser
(3) Reduction in cost
(4) Availability of raw materials

All of us remember the first automobile, a clumsy vehicle, with large cylinders cast singly or in pairs, make-and-break ignition, an open fly wheel of cast iron, chain and friction drives of one sort or another. But people bought them because they had no basis of comparison, and because they were the best thing available to do the job for which they were intended. It wasn't long, however, until somebody came along and said, "We won't use these open chains any more but will use gears and enclose them." Another man said, "We will eliminate this unreliable make-and-break system and will make a more dependable sparking arrangement."

Later, after many people had broken their arms in cranking their cars, the self-starter came into being, and, as competition became keener, prices were brought down, the development in the motor car industry became faster and faster until today the modern motor car, through these different stages, has become one of the outstanding American developments.

Through the development of the modern motor car, many things were learned about fabrication of metal, design of power-transmitting units, metallurgy, finishes of metals, etc., which gave the pioneer stoker manufacturer a tremendous head start. Our job as manufacturers has been to take this mechanical information and assemble it to help us design a machine to do a job of coal burning. But even with all the help that the automotive and other industries gave us, there

*I gathered this information with the cooperation of my friends in the following companies of the Stoker Manufacturers Association:

Anchor Stove & Range Co.	Iron Fireman Mfg. Co.
Auburn Foundry Co.	Link Belt Co.
Conco Corporation	Peerless Mfg. Co.
Econocol Stoker Div. Cotta Transmission Corp.	Combustioneer Div. Steel Products Eng. Co.
General Motors Sales Corp.	U. S. Machine Corp.
Freeman Div. Illinois Iron & Bolt	

†Vice-President, Holcomb and Hoke Manufacturing Company, Indianapolis, Indiana.

were a lot of problems to be worked out in the burning of coal, especially in the small domestic stoker.

A lot of you will remember some of the first stokers. How strange they would look to us now! Transmissions with clutches and gear shift levers on them—transmissions with as many as sixteen gears—large repulsion induction motors—heavy cast air ducts—large diameter feed worms—to say nothing of oil leaks, and the lack of any thought given to the appearance of the job when finished.

We have come through many years of development and research in the stoker industry, and while there may seem to be few changes visible to the layman, there are many hidden developments and improvements, which all contribute to a lower-priced stoker and one which gives far greater satisfaction than earlier models.

I'll speak of a few of the improvements that most responsible stoker manufacturers have incorporated.

In talking about these improvements, it is well to divide the stoker into two general divisions—the feeding mechanism, or the part outside the firebox—and the burning mechanism, or the part inside the firebox.

There are many stoker feeding mechanisms today that are so efficient that they will feed coal through the stoker and out the top of the retort with a motor as small as $\frac{1}{50}$th horsepower. This of course does not include the turning of the blower or fan.

What are the few fundamental characteristics, dimensions, or combinations that have made this possible?

First, the efficient design of transmissions.

Second, a reduction of friction on the feed worm section in the hopper. This has been done in many ways. Some companies have shortened the length of their hopper base; others have made the diameter of the worm in the hopper base smaller; some have changed the pitch of the worm, but they all have had in mind the reduction of friction and the breaking of coal by the worm as it turns in the hopper base.

Third, most companies have found that unless the worm and worm housing fit snugly at the point where the worm leaves the hopper, too much coal may be drawn into the worm housing or feed tube, thereby causing a packing condition in the worm housing.

Fourth, there must also be a definite relation between the pitch of the feed worm and its diameter.

Fifth, the curvature of the retort, where the direction of flow of the coal changes from horizontal to vertical, must be correct; and the length of the feed worm, or rather, the length extending into the retort

base, has a very definite bearing on the ease with which the coal may be fed to the fire.

If a mistake is made on any one of these design characteristics, trouble may result, and, while these things may sound simple as I tell them to you, many hours of work, experimentation, and field service have gone into deciding just the proper way to eliminate these troubles, and I am sure that still further improvements will be made.

Now, let us consider the burning department—the retort and tuyeres. A stoker may feed coal very easily and with very little power consumption when there is no fire in the furnace or boiler, and when this same stoker is put under fire, a binding action which stops the stoker is encountered under certain conditions. This, we find, is due to swelling of the coal in the bottom of the retort, even down in the throat. When coal is heated it has a tendency to swell. Swelling depends on the characteristics of the coal and the rapidity with which it is heated, but from a practical angle the cooler the coal can be kept until it gets up into the burning zone, the better operation we will get, and the easier it will be to feed coal under all conditions.

To help eliminate excessive heating and swelling of the coal before it comes into the tuyere or upper section of the retort, this year, for the first time, cooling fins have been added to retorts and windboxes. This assures easy feeding of coal even under high heat conditions. Keeping the coal below the temperatures at which swelling occurs also helps to eliminate coke trees, and in turn gives better distribution of fuel over the fuel bed.

The practical, tangible results that the purchaser may expect from these refinements and developments I have just talked about, are as follows:

First, less power consumption, hence lower electric bills; second, longer life for the stoker transmission; third, longer life for the feed worm; fourth, fewer service calls; fifth, fewer parts replacements; sixth, quieter operation; seventh, less first or initial cost.

Now let us look at some developments in more recent years which deserve mention.

Let's start with the *finish* we now find on stokers. It is smooth, hard, and durable, and comes in attractive colors, some of them heat resistant. With a finish so smooth and hard a stoker is easily kept clean.

Motors.—Today the electric motors are simpler in construction, especially in the switching mechanism, with positive protection for low or high voltage or when stalled. Too, these motors are cheaper and the user is benefited by the reduced cost.

Transmissions.—The transmissions are simpler—they have fewer gears—and are more efficient. They do not leak oil, are quieter, and will last longer.

Fans.—Some fans now are die cast, which means a cheaper fan for the manufacturer to purchase, and this saving is passed on to the consumer. The fans are quieter, have better characteristics, and usually deliver more pressure.

New inlet dampers.—Many manufacturers are using and others are experimenting with inlet dampers, which reduce the noise of the air going into the fan.

Automatic air control.—Much work has been done on automatic air controls. They are designed to work on different principles, but all are intended to give volume and pressure commensurate with varying conditions of the fuel bed.

Delayed opening and closing air damper.—This is usually an electrically operated damper, which is connected in parallel with the motor on the stoker. When the stoker motor starts, the damper does not open immediately, but in a few seconds or minutes it opens slowly. When the stoker motor stops, the damper stays open for a few seconds or minutes, and then closes slowly. The advantage of this type of damper, I am told, is that it helps to eliminate fly ash, and it also cuts down the smoking period after the stoker stops.

Metalized tuyeres.—Some companies are treating their tuyeres with metal to make them last longer. This metal, when sprayed on the tuyeres, keeps down oxidation, thus lengthening the life of the tuyeres.

Feed worms without centers.—Quite a bit of experimenting is being done on centerless feed worms. The advantage in these worms is that they can be made much smaller than the standard feed worm, and still carry the same amount of fuel with less crushing.

Controls.—Improvements have been made in thermostats. They are now made so they can be adjusted for large or small homes to eliminate overruns. Hold-fire controls are now being made without clocks as well as with clocks. The prices of controls have been considerably reduced.

Bunker-feed models.—I think most of the manufacturers today are making bunker-feed models in practically any size.

Bin-feed models.—You can now get from most companies the straight-line bin-fed models, or the transfer type where the transmission and blower are between the bin and the furnace.

Hot water heater units.—Many manufacturers today are making self-contained units for heating hot water. I understand they are very successful, and the market is quite large for such a unit.

Boiler burner units.—Boilers with the burners built in with them are available either in the bin-feed or hopper-type model.

Stoker furnace units.—These are available in bin-feed and hopper models. They have been on the market for quite some time.

Stokers for cook stoves.—I saw one the other day which could very easily be used as a watch fob.

The new developments of companies who are members of the Stoker Manufacturers Association, are as follows:

U. S. Machine Corporation, Manufacturer of Winkler Stokers

Domestic series.

Improvement in appearance by new trim, Morocco finish, and slight changes of line.

The addition of a new adjustable inlet damper, which has the effect of sizing the fan for a given set of conditions. This damper has silencing characteristics and is extremely easy to adjust.

The improvement upon their Eez-Air control, which results in greater fly-ash elimination, and improved hold-fire conditions by eliminating the initial blast of the fire normally accompanying the starting of a stoker.

Reduction of noise level by the use of acoustical engineering at several points.

Improvement upon automatic air regulation by means of adjustments, bearings, etc.

Commercial series.

A complete, new, automatic air regulator; new adjustable intake silencing damper; complete new burner on 150-pound-per-hour model, with improved coal distribution characteristics; increased air capacities.

Industrial series.

A completely new automatic air regulator and adjustable intake silencing damper; increased air volume on several models; improved appearance, associated with production tools for blower housings, hoppers, motor covers, etc.

Self-feed series.

Domestic series as previously produced, except with new adjustable inlet damper. A new commercial series of Self-feed models in 75, 100, and 150 pounds-per-hour capacities, similar in design to the current domestic series.

Manufacturing improvements on the industrial Self-feed models in capacity from 200 pounds to 800 pounds per hour.

Bin-base series.

Entirely new Bin-base units in domestic, commercial, and industrial series.

Conco Corporation

The Clipper Stoker.—This is a brand-new stoker in the line, developed primarily to fit in the modern, small, steam and hot water boilers which have been brought out within the last two or three years for use in the modern four to six room, well-insulated house.

The Commander Stoker.—Particular attention has been given to the retort design in order to burn efficiently the majority of the new, highly prepared stoker coals being put on the market. As far as possible, parts are made interchangeable, to reduce production costs and dealers' inventory, and to give quicker service to customers.

The Fuel Miser.—A mechanism that can be made a part of any Conco domestic or commercial stoker to control the burning rate of that stoker. It

(1) decreases stack losses;

(2) eliminates severe thermostat over-runs;

(3) maintains a level fire bed regardless of extreme weather conditions;

(4) reduces retort temperature and coking materially;

(5) makes the use of day and night control much more desirable and efficient;

(6) saves electicity.

This mechanism provides modulating control of the stoker by automatically varying both the coal- and the air-feeding rates in accordance with the demands made upon the stoker.

The Link-Belt Company

First, and perhaps most important, is their development of the automatic air control. This started out as a rather crude affair located in the windbox between the fan and the air chamber. Recent improvement has changed the controlling medium to the inlet of the fan, and a patent has been granted on the method of opening and closing the inlet shutter. This new method makes it possible to exert a variable pressure on the diaphragm which opens and closes the shutters, with a resultant lowering of air volume on thin fuel beds, and increasing of air volume as fuel beds become thicker or more resistant. The advantages to the user from this type of air control are the reduction in the amount of noise, the reduction in the amount of horsepower required to drive the fan, the assurance of more nearly the proper flow of air to the fire, based on fuel bed conditions, with a consequent increase in overall efficiency, and a reduction in the amount of fly ash encountered in mild weather.

The next development of consequence has been the increase in strength of the drive unit and other stoker parts to the point where it is possible to use thermal guard protection in the motor for overload.

Some improvements which are more or less paralleled by other members of the industry, would, of course, be the development of simplified hopper model stokers, selling at lower prices within the reach of the most modest income, and the continued improvement in the design of automatic bin-feeding units which brings bituminous coal one step nearer to giving completely automatic heat.

Illinois Iron & Bolt Company—the Freeman Stoker

With the exception of minor changes and improvement in general appearance, the principal items which would fall under the new product listing for this year, are as follows:

(1) A line of stoker-fired hot water heating units, consisting of two sizes, one suitable for 240 ft. gravity hot water, and the other for 400 ft. gravity hot water, both of which are listed in net standing radiation. These units are also suitable for heating the domestic supply of hot water. They give the public an opportunity to obtain a complete, stoker-fired hot water heating unit at an exceptionally low price, and are suitable for installation in the thousands of small homes being constructed today. The large one is sufficiently large to take care of the heating load, as well as the domestic supply of hot water, in many of the buildings.

(2) They also have developed this year a new stoker considerably smaller in size than anything they previously built in domestic stokers. It has a coal-burning end considerably smaller than previous models, and is much more suitable for installation in small heating plants.

The use of this stoker makes it possible for the small building owner to purchase a stoker and heating plant for less money than was possible previous to the bringing out of this new 15-per-hour unit, as the large coal-burning end on the stokers made it necessary to purchase a heating plant having a large firebox in order to get satisfactory stoker performance, regardless of how small the building might be.

The Auburn Foundry, Inc.

The Auburn Foundry, Inc.—manufacturer of the Auburn Stoker—has brought out the Auburn Special Stoker Furnace, which is manufactured in one size, and regular equipment includes 25-35 pounds DXLD Auburn Bin-Feed Stoker.

The Anchor Stove and Range Company

The Anchor Stove and Range Company has brought out a new winter heating and air conditioning unit called the Anchor-Aire. In bringing out this unit, Mr. C. M. Lewis, sales manager, makes this explanation:

"We didn't think by any means that we could build a furnace better than any reputable furnace man, neither did we believe we could build a fan or fan housing any better than a reputable fan builder, but we did believe if we had the several parts correlated in such a fashion that all sizes and capacities would have a direct and definite relation, then the entire package unit would be a far safer bet for us to sell and a safer bet for the consumer to purchase than the jig-saw type which before that time was the only thing available.

"The importance of capacities of the several component parts and their relation to one another cannot be overlooked. As the manufacturer of the complete unit we know, for instance, the stoker will deliver the rated capacity of that stoker. The fan is not left to haphazard selection by either the purchaser, the dealer, or the installer, but instead, after it has been predetermined that a specific C.F.M. is necessary in relation to a specific rated pounds of coal per hour, all in turn with a direct relation to size and heating surface of the heating element itself, the fan capacity as supplied with the original equipment will deliver the rated C.F.M."

The Econ-O-Col Stoker Division of the Cotta Transmission Corporation

Particular attention is called to the new "Dynamatic Power Unit," which is composed of a continuous feed transmission using the strongest of alloy steels and made to automotive standards. In this Power Unit is also incorporated the General Electric belt tightener base motor, which automatically keeps the proper tension on the belt, as well as facilitating change in coal feeding rate. The new "Automatic Torque Clutch" incorporated in the driving pulley of the transmission, automatically disengages in the event that some foreign object impedes the flow of coal in the coal tube. At the time of disengagement, an electric switch is tripped, automatically stopping the fan as well as the flow of coal, thus preventing the fire burning down into the retort.

The feed screw has a special patented design, being of reduced diameter at the hopper end, which prevents the coal segregating in the hopper, and overcomes the common occurrence of the segregating and packing of fine coal in one corner of the hopper.

The air volume control is automatic, maintaining proper flow of air to the fuel bed at all times. It automatically shuts off natural draft when the stoker is not running.

Steel Products Engineering Company

Mr. Goddard of the Steel Products Engineering Company, manufacturer of Combustioneer Stokers, tells me they are making improvements all the time, particularly on automatic dampers, tuyere designs, and bin-feed stokers, both the pull-through and transfer types.

Peerless Manufacturing Corporation

Peerless Manufacturing Corporation has added a new, small, 20-pound-an-hour domestic machine to its line for 1941.

Holcomb & Hoke Manufacturing Company

As for the Holcomb & Hoke Manufacturing Company, most of our development work last year was done in improving the design of our burner head, and in providing cooling mediums to keep the expansion of coal to a minimum in the retort and throat.

Much time, as well as money, is being spent by the stoker industry in development and research. I am sure as the years pass you will find this industry continuing to give the buying public more for its money, better equipment, and equipment more automatic in operation, which in turn will keep *coal*—where it should be—*out in front as a fuel.*

X. SALES CONTROL

ARTHUR C. WEICK*

From time to time certain individuals have misunderstood the character of my work. I have received phone calls asking for tips on the stock market. There is of course no direct comparison which can be made between a sales counselor and market analyst, such as myself, and a stock market analyst, except possibly one: in the stock market, the bulls and the bears are not responsible for as many losses as the bum "steers."

I shall try to give you a "good steer," and I sincerely hope every one of you will take away some worthwhile idea. Our difficulties in the coal business, which became more apparent with increasing oil and gas competition, have been due not so much to mistakes or bum steers as to the need for more merchandising, sales promotion, advertising, education, and selling plans which work.

One of the most important problems is customer relations. To control sales and profits it is necessary to control methods of promotion for increasing new customer volume and old customer volume. New business plus repeat business, minus expenses, equals profit or loss. It's a seemingly simple formula. Let's examine these factors in the light of customer relations.

Selling New Customers.—First, let us discuss new customers. A market study recently revealed that one of the largest businesses in the United States was on the decline because during the depression and some years following they neglected to sell enough new customers to offset their customer mortality. For business to grow continually, it is necessary to obtain more new customers each year than you lose. And as competition becomes keener and the expense of getting new customers increases, it is important to adopt more efficient methods of selling. No business today can afford to carry dead weight in sales personnel, or to use haphazard methods of promotion.

Too few of us can answer certain important questions. What was your customer turn-over last year? How many new customers did you secure last year? What did it cost you to sell each new customer? Did you obtain more new customers than you lost? If not, and you continue to get fewer customers than you lose, your business will decline. Do the new customers you are getting this year offer as

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much sales volume as the customers they are replacing? If their volume is smaller on the average, more new customers will be needed to fill the gap. How much is a new customer worth to you? Some merchants believe that a new customer is worth the net profit for one year. Do you spend your net profit for one year on new customer business to obtain more new customers? Do you have a definite budget for sales promotion, advertising and selling, designed to attract new customers? If not, why not? Many dealers have not taken advantage of using direct mail. Some dealers haven't spent enough money on building prospect lists, and others do not properly follow up their mailings with personal solicitation. Lack of adequate follow-up with personal solicitation has caused much direct-mail advertising to be wasted.

The better coal merchants are trying to get down to fundamentals in their thinking. It is only as we grasp and meet these fundamentals that we get sales control. Do you study your prospects in your particular territory? Have you actually called on every laundry, dairy, and greenhouse in your community? Or are you just getting the little customers? or only the big customers? More market research is desirable. Sales control is impossible without it.

Are you careful in the selection of your personnel? How about the girl in the office, the salesmen, and the truck drivers? With competition what it is today, no dealer can afford to be too careless in the selection of employees, drivers, and salesmen. Recently one dealer interviewed 75 girls to hire two to sell furnace cleaning over the telephone. Have you been as careful to get a good sales girl in your office? The two girls selected sold over 2200 furnace cleaning jobs in the past relatively few weeks. They sold as high as 50 per cent of the people to whom they talked.

What do you or your girl say over the telephone when a new customer calls? Does she say "hello"? The word "hello" does not make a good impression. It does not answer any question. It does not tell the person calling who you are. Does she know a sales talk which she has prepared to tell quickly to a customer who inquires? Do your salesmen have prepared conversations for new prospects who inquire by telephone? Isn't this as important in the getting of new business as the proposition itself?

What proposition are you selling? What are the best selling features of your product? For what do people look when buying coal, a stoker, a furnace, or an electric refrigerator? From a nation-wide survey among refrigerator dealers, General Electric reports that the six best selling features were found to be as follows: first, brand name; second, equipment, interior arrangement; third, price; fourth, style and beauty; fifth, economy and performance; sixth, construction.

Are you selling a wide variety of coal or are you specializing in the sale of one or two kinds of coal? Do you have the exclusive franchise on a certain kind of coal? How can you do a concentrated, efficient selling job unless you specialize? Do you inspect the heating plant of a new customer to make that customer feel that you are giving him the kind of coal best suited for his type of equipment?

More and more coal men are selling stokers, furnaces, barometric controls, attic fans, insulation, and other equipment to broaden markets. There is a tendency for coal companies to branch out into the handling of new products. Some coal and ice companies have even gone into the sale of frozen foods, actually delivering them from house to house. Likewise, some are selling Deepfreeze, a cold storage locker which preserves and keeps foods ever available in the home without spoilage.

There are many ways to attract new customers. Whatever you do, let me suggest that you adopt a definite sales plan for your business, if you have not done so already. New customers are the foundation of business growth.

Established Customers.—What do you do to keep your old customers satisfied? Every new customer, unless he is new in the community, left another supplier because he was dissatisfied with the coal, with the price, with the service, or with some other phase of their relationship. No fuel or equipment is any better than what the customer gets out of it.

More effort is now being made to train the stoker user, to get him started off right, to see that he is completely satisfied. Service men are able to get more leads. Special men are being trained for such work, to follow up the installation crews, to show the buyer how to operate the stoker and then to call upon the users at periodical intervals.

If you want to prevent service calls, and perhaps two out of three could be eliminated—or if you want more leads—here is an answer. If you take care of the customer, the customer will take care of you. Have you ever asked yourself—what are we really offering in service? What chance has much of our coal or equipment to satisfy the consumer?

How many of us noticed the Kopper's survey covering the inspection of 26 000 heating plants as reported in the May issue of *Coal Heat?* Just 5 per cent were found in good condition. As high as 75

per cent of the furnaces sold during the depression, and 55 per cent of those sold in the past 12 years were replacement jobs. Fuel is no better than the equipment in which it is used. Do you inspect your customer's equipment and give your customers the benefit of your knowledge and understanding?

One coal merchant made a recent analysis of his lost customers. Out of 286 customers which he lost, approximately half had stayed with him only one year. Another 25 per cent remained two years, and the remainder three years or more. This is a very high turn-over. He has to sell four new customers to get one who will stay with him at least three years.

A further analysis showed that about half of the lost sales were secured through the office rather than from salesmen outside. This was an indication that the office salesman was poorly trained, and perhaps not the right person for the job. A further study of lost customers in each salesman's territory showed that extremely few customers were lost in four territories, whereas a relatively large number were lost in five other territories. This seemed to indicate that some salesmen kept their customers satisfied whereas others did not.

While these lost customers consumed various amounts of coal, varying from 1 to 21 tons per year, most of the customers were quite small. Perhaps this accounted in some measure for their neglect. It is also an interesting fact that these lost customers were approximately evenly divided between charge accounts and C.O.D. accounts. A more important fact, however, was that a large number of these lost customers had used from two to five different kinds of coal. Obviously a customer who now and then shifts from one kind of coal to another needs to be serviced. He does not yet know which coal is best for his equipment and pocketbook. Most of these lost customers left the company because of service neglect, oil or gas competition, or bought elsewhere to meet reciprocity, or the fuel was unsatisfactory. Good selling and servicing can materially lengthen the time a customer will buy from one company.

Budgeting Expenses.—Now before I leave this platform I would like to offer you a simple, constructive suggestion. As a coal merchant you may make a net profit of 20¢ a ton or 70¢ a ton, more or less, depending upon various factors. Let us assume for the sake of illustration, using a round figure, that it is 50¢ a ton in your particular business. Let us assume again that your customers will stay with you five years on the average and buy ten tons of coal per year. Certainly these are figures every dealer should know about his own business. If you do not have them I suggest that one of the first things you do when you get back to your office is to study your records. Too often our bookkeeping doesn't tell us what is going on. Ten tons a year for five years is 50 tons per customer, and at a net profit of 50¢ per ton, your net earnings would total $25.00 per customer. If you allow your first year's net earnings from new customers to be used as a promotion fund, you will have $5.00 per customer for the budget.

Next it is necessary to determine how many customers you need to compensate for your customer mortality each year, and to give you a margin upon which your business may develop. Suppose that you need 100 new customers annually. Then you can afford to spend $500.00 on sales development. Knowing that this is your budget you are now in a position to lay out a definite plan of selling sales promotion and advertising that will give you the required results within this expenditure.

After figuring your coal budget and determining your plan for selling coal, then estimate a similar budget for your stoker business. How much is a stoker customer worth to you? If your net profit per stoker sold is $25.00 let us take, say, one-half of this for the sales promotion budget, or $12.50. If your quota of stoker customers is to be, say, 40 stokers annually, you would have $500.00 for your promotion budget. This $500.00 plus the $500.00 from your coal budget would give you a combined coal and stoker budget of $1000.00. Base your figures on your own records. How much do you want?

It is wise to adopt a definite budget based upon your own knowledge of what your records show you must secure in the way of new business, and what you can afford to spend. Then plan your sales effort and work that plan to build your business in a substantial, profitable way. I think you will agree that it is fundamentally necessary to see that employees' sales and advertising policies produce results within a reasonable budget. Budgetary control is necessary. Employee education is imperative. If you follow the points we have previously discussed to promote new customers and to service and protect established customers, your customer relationships will improve, and your business will expand and grow. This is sales control. Sales control is not merely a system of records. Its essence is management. This will enable you to smile at competition and feel "the cool, calm confidence of Christian holding four aces."

XI. THE ST. LOUIS VICTORY OVER SMOKE

A. S. LANGSDORF*

Just about 40 years ago the City of St. Louis began to make preparations for its ambitious World's Fair to celebrate the one hundredth anniversary of the Louisiana Purchase of 1803. Those who saw that fair will long remember it as an architecturally beautiful achievement that brought together not only choice examples of the world's best in art, industry, and science, but also congresses and conventions of the leading minds from all the nations of a world then fortunately at peace. And it was because the city anticipated its role of host to great numbers of visitors from our own country and abroad that a wise city administration foresaw the need of clarifying a water supply that until that time had been a by-word in all the other cities that were blessed with a less turgid source than the muddy Missouri-Mississippi. It is not necessary to bore you with details of that undertaking. Suffice it to say that the experiments that were then undertaken were crowned with success just in time to provide the city with clear water on the eve of the dedication of the fair. I have always believed that the permanent value of the achievement of a clean, wholesome water supply far outstrips the transient glory of the fair itself. The process developed at that time, and subsequently still further improved, has been an inestimable boon not only to the City of St. Louis but to the numerous other communities that quickly adopted the method to their own conditions. That method was based upon the idea that the problem had to be attacked at its source by treating the raw river water at the main pumping station. Prior to that time each individual household had been compelled to meet the problem as best it could, by filtering or boiling, or doing both to the liquid mud that came from the taps—how ineffective these half-way measures were is strikingly shown by the precipitous disappearance of typhoid fever from the vital statistics immediately after the community had acted as a unit.

These somewhat ancient facts are mentioned because they illustrate very well how slow we are to learn by experience, and to carry over to new fields the hard-won lessons learned in others. Without attempting to philosophize, the point may be made that it took us nearly 40 years to realize, or at least to act upon, the theory that a

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smoky atmosphere, like turbid water, must likewise be attacked at its source, not by temporizing with the results after the smoke has been produced. That decisive step has been taken, and a decisive victory has been won, though it is not yet complete, nor is there entire certainty of its permanence. What has been accomplished is a conclusive demonstration that the problem can be permanently solved by unremitting vigilance and conscientious administration of regulatory ordinances, combined with a willingness on the part of citizens to exchange the hidden costs of obvious dirt and grime for the very immediate, but lesser, costs of generally unnoticed cleanliness.

St. Louis had earned for itself the unenviable reputation of being one of the smokiest and dirtiest cities in the country. Its smoke problem did not differ in kind from that of other communities in the soft-coal region, but it did differ in degree because of very definite topographical and meteorological conditions. The extensive use of high-volatile Illinois coal, high in ash and sulphur, aided and abetted by a very low average wind velocity, gave rise to a particularly persistent smoke pall throughout the heating season. Had we been granted the breezes that give Chicago its nickname of the "Windy City," this story would not need to be told.

Efforts to abate the smoke nuisance have been widespread and numerous over a very long time. St. Louis has had its full share of them, dating back nearly 80 years. Their history has the sameness that one would expect who subscribes to the notion that history repeats itself. A group of citizens, generally few in number, driven to desperation by the nuisance, launches an abatement campaign, reaches the peak of its efforts in pushing through a smoke abatement ordinance that puts the burden of enforcement upon a Smoke Commissioner who is given no real power, then lapses into somnolence, thoroughly tired out, and confident that the new legislation will do the trick, in spite of obvious public indifference. That has been the story over and over again. I took an active part in one such campaign that was launched in 1926 and that kept actively at work for nearly eight years. The original theory of that campaign was that the smoke problem could be solved by a campaign of education, involving wholesale instruction of householders, janitors, and firemen in the art of hand firing of stoves and furnaces. Nearly $200 000, raised by popular subscription, was spent in giving such instruction in a model firing school, and in private homes, apartments, and industrial plants. There may have been some improvement—for the time the money lasted—but one had to be a real optimist to see the improvement. But when it was all

over, and the inevitable new smoke ordinances had been passed, the conditions became worse than ever before.

The experience gained in that campaign taught several lessons, which are embodied in some of the final records of that Citizens' Smoke Abatement League. They are

(1) that smoke elimination, not mere abatement, is the goal to be achieved;

(2) that campaigns of education in hand firing are completely futile and an utter waste of time and money, for the reason that those who are initially trained either move away, to be replaced by new ignoramuses, or they lapse into indifference;

(3) that smoke elimination, to be permanent, demands

(a) that high volatile fuel be burned in mechanical stokers that insure smokeless combustion; or

(b) that smokeless fuel be used in furnaces that are incapable of smokeless operation with high volatile fuel.

To these three conclusions I added a fourth, the truth of which is inherent in item (3); namely, that while the elimination of smoke is necessarily based upon sound engineering principles, it is fundamentally an economic problem because of the extra cost that must be borne to achieve the solution. Smokelessness must be attained by building it into the furnace or into the fuel, just as clear water must be prepared before it is served to the consumer, and the consumer must be willing to pay for the extra service. This consideration was incorporated in an open letter sent to the St. Louis newspapers in 1934, but it received only scant attention. At that time the newspapers were editorializing on the theme of a smokeless fuel to be miraculously developed from Illinois coal at a price lower than that of the raw fuel.

The first noteworthy advance in the St. Louis attack upon its smoke plague may fairly be said to date from the inauguration of Mayor Bernard F. Dickman, who recognized the challenge that the problem presented to the municipal administration. A survey conducted by a combustion expert led to the passage in 1937 of a new and improved ordinance, which included among other features the provision that certain types of fuel be washed to reduce fly ash and sulphur. It was not claimed that this provision would of itself eliminate smoke, but that it would improve the quality of fuel used in stoker-fired furnaces. Incidentally, but in reality a matter of greatest importance, this washing clause for the first time established the right of the community to control the type of fuel that might be burned within the corporate limits. This clause was attacked in the Federal

Courts, but the injunction that was asked against its enforcement was denied, so the principle may be said to be fairly established.

Mr. Raymond R. Tucker, who was appointed Smoke Commissioner to administer the 1937 ordinance, knew very well that the major source of the city smoke was the thousands of small hand-fired stoves and furnaces in residences and apartments, and that the only way to control them was through the use of smokeless fuel, the use of which was not, however, mandatory under the ordinance. He nevertheless refused to issue permits for hand-fired furnaces unless the owner filed an affidavit certifying that low volatile fuel would be used. A protest against this ruling was upheld by the Appeal Board provided for in the ordinance. It was this situation which led to the effort of the Dickman administration to obtain from the Illinois Legislature the authorization and the funds for a research program looking toward the production of a suitable smokeless fuel from Illinois coal. That legislation was duly passed, and the research program has since been in progress under the general direction of Dr. Leighton.

The ordinance of 1937 did not, of course, eliminate smoke. Pure air cannot be obtained merely by passing a law. What actually happened was that in the autumn and early winter of 1939 the city was afflicted with a long succession of the worst smoke palls in its history, the result of a protracted spell of windless weather. Pictures of those midnight blackouts published in the newspapers and in magazines having a national circulation focussed attention upon the plight of the city to an extent that at long last aroused the people and the press to the realization that drastic action was necessary. The newspapers, all of them, were particularly vigorous in demanding a solution of the problem, and two of them proposed solutions in detail; and they kept hammering on the subject day after day, in unison, a thing that had never before happened. The result of this large scale agitation was the appointment by Mayor Dickman of a special committee to report necessary remedial measures.

This special committee, under the able chairmanship of Mr. James L. Ford, Jr., met at frequent intervals from December 11, 1939, to February 24, 1940, when the final report was submitted to the Mayor. The committee had held hearings at which all who had any suggestions to make were given the opportunity to present them. The gist of this report was that mechanical equipment mut be used for burning high volatile fuel, and that smokeless fuel must be used in hand-fired equipment. The recommendations of the Mayor's committee were fully supported by an independent report prepared by a committee of the Associated Engineering Societies of St. Louis.

To its everlasting credit, the press of the city enthusiastically and continuously backed up these recommendations, and on April 8, 1940, the Board of Aldermen passed the ordinance which incorporated these recommendations into the present law. The essential provisions of the ordinance are here summarized:

(1) It prohibits the emission of smoke of a density of 40 per cent or more.

(2) Definite limitations are placed upon the discharge of fly ash from plants burning fuel in suspension or partially in suspension.

(3) It re-enacts the washing clause of the ordinance under which the Division of Smoke Regulation has been operating.

(4) It defines smokeless fuel as any fuel which contains 23 per cent or less volatile matter on a dry basis, and establishes certain restrictions for the use and distribution of all fuel in the City of St. Louis.

(5) It grants to the city the right under certain circumstances to declare an emergency and purchase fuel for distribution through the established channels of trade or otherwise.

(6) It specifically states that the railroads are subject to the same requirements as any other user of fuel in the City of St. Louis.

(7) It makes it mandatory for those installing, repairing, or reconstructing any fuel-burning plant to obtain a permit for such work and the approval of the Division of Smoke Regulation before such work is done.

(8) It requires the Division of Smoke Regulation to make an inspection upon all work which is being done under a permit, and to issue a certificate stating that the work that has been done meets the approval of the Division.

(9) It requires all those selling fuel-burning equipment to report their sales to the Division of Smoke Regulation in writing after such sales have been made. This provision does not apply to wholesale transactions made for the purpose of resale.

(10) It prevents the Building Commissioner from issuing a building permit for any structure wherein the plans show a chimney or smokestack unless such chimney or smokestack has been approved by the Division of Smoke Regulation.

(11) It prohibits the Commissioner of Smoke Regulation from issuing a permit for any new fuel-burning installation unless it is equipped with mechanical fuel-burning devices or uses a fuel containing 23 per cent or less volatile matter.

(12) It establishes fees for the issuance of permits and certificates ranging from $1.50 to $5.00.

(13) It grants the right to appeal from any decision of the Commissioner of Smoke Regulation within ten days from such decision.

(14) It authorizes the Commissioner of Smoke Regulation to seal any fuel-burning apparatus if three violations of the law are recorded in any twelve consecutive months. Before such sealing however, a hearing must be held in order that the violator may have an opportunity to show cause why such action should not be taken.

(15) It prohibits interference with the inspectors of Smoke Regulation in the performance of their duties at all reasonable hours, and states that such interference is a misdemeanor under the terms of the ordinance.

(16) It establishes penalties for violations of the ordinance ranging from $25 to $100.

(17) It establishes a defense according to State statute.

(18) The ordinance states that it shall be a good defense against any violation of the ordinance if it can be proven that an adequate supply of smokeless fuel is not available, and that there is no known practicable device, appliance, means, or methods to eliminate the nuisance.

This ordinance, be it noted, was passed in April, 1940. Mr. Tucker and his small, but able and well selected, staff had the following summer in which to get ready for the heating season of 1940-41. The job of organization and administration that they accomplished brought such amazingly successful results that they must have been as much astonished as were the citizens generally. I confess, for my part, that, while I expected an appreciable improvement, the results far surpass anything that seemed within the bounds of possibility. The autumn of 1940 came, the winter followed, but the smoke of former years was so conspicuously absent that one could hardly believe the evidence of his eyes—and nose. It was as truly a victory over the atmospheric dirt as the similar victory of 1904 over the mud of the river water.

I well remember some of the unpleasant aftermaths of the clarification of the water supply. Certain business interests that had flourished from the sale of individual household filters indulged in a campaign of vilification against the new process. They claimed that the addition of chemicals to the water endangered human health, and caused the death of fish in aquariums. One newspaper at that time devoted large amounts of space to such canards. The opposition quieted down after a time when it became evident that human health

had actually been promoted, and that fish could still be raised in an element through which they could actually be seen. There has been some evidence of an analogous campaign since the battle against smoke has been shown to be successful. It has taken the form of a sudden access of pity for the poor who have to pay somewhat more for good fuel than they formerly paid for bad. This issue was injected into the recent mayorality campaign, and there are some who aver that Mr. Dickman's defeat was due to this feature. I am one of the many who do not believe that this factor can explain the heavy Republican majority; on the contrary, there are several other weighty reasons, any one of which is more convincing than price of fuel. But you have asked me to speak about the victory over smoke, so I refrain from injecting any discussion of politics.

You will want to know what are the facts upon which it is possible to aver that there has been a victory over smoke. If any of you had occasion to be in St. Louis last fall and winter, you have one answer in the evidence of your own eyes. One does not need the evidence of dust counts and soot-fall measurements when one can see bright sunshine and when his collar remains clean. Speaking from personal experience, I had occasion to travel more than usual during the season just passed, and it was a revelation to come into the city on a train and to find visibility unobscured by murky clouds of smoke. In fact, the air was actually clearer inside the city limits than in the numerous surrounding suburbs. This fact, and it is a fact, disposes of the argument that the cleanup in the city was principally due to a higher than average wind velocity; for if wind had been the determining factor it would have been operative to a greater degree in the suburbs than in the city.

Another personal observation: the interior of my home, situated in one of the older residential districts, has always heretofore been so begrimed by Christmas time that it has been necessary to wash at least the living room ceiling, walls, and wood trim; and by springtime the thing had to be done over again throughout the house. This year there has been need for no more than the ordinary spring housecleaning that all good housekeepers take for granted. Moreover, curtains and drapes that in the past could stand upright after two weeks of dirt catching, were fresh and reasonably clean after two to three months of undisturbed use. This marvelous experience was a favorite topic of feminine conversation throughout the city, at least in the circle of people who are my friends.

You have perhaps seen the before-and-after types of photographs that had wide publicity in newspapers and in *Life* magazine. Trick photography is so common that such exhibits have little standing as legal evidence. But I am here to testify that these pictures are not faked, though they may have been taken under extreme conditions in both directions.

Here are other bits of evidence:

Excerpt from a letter written by a leading ear, nose, and throat specialist practising in St. Louis and Belleville, Illinois:

I have been practising in the ear, nose, and throat profession in this city since 1912 and I have noticed something unusual this year over every other year since I have started in this profession; that is the amount of smoke, dirt, and soot that I observe in the inside of people's noses. The first one-half or three-fourths of the inside of the nose is known to ear, nose, and throat men as the vestibule. Heretofore in the winter every St. Louisan that I have treated had a large amount of dirt, smoke, and soot in the vestibule of the nose, so that when a treatment was needed it was always necessary to wash out this space with soap and water. During this past year I don't think that I have had to do this more than twice. I also have an office in Belleville, Illinois, where the condition of dirt, smoke, and soot in the nose is still prevalent just as it formerly was in St. Louis. This, of course, may not be of any great importance to you, but I think that it is well worth reporting. The fact that these noses were dirty inside meant that the natural function of the nose did all that it could to eliminate all of the smoke from the air, but a certain amount of it naturally got into the deeper tissues, namely the lungs.

Excerpt from radio address of Dr. George T. Moore, Director of the Missouri Botanical Garden, April 6, 1941:

Until this last winter, every year since 1937 the amount of sunlight available during that half of the year when it is most necessary has always been greater in the country than in the city—some years as great as 150 hours. But this winter, up to the first of March, the record shows only 23 hours more at the Arboretum than in town. One would always expect slight differences due to local thunder storms, but when from September to March this year there was over one hundred hours more sunshine in town than in 1939-40, it must mean that something has happened. Something that in all previous seasons of which we have a record did not occur, or rather something which did occur, preventing St. Louis from getting the sunshine to which it was entitled. There can be but one answer—smoke.

Furthermore it is not without good reason that the publicity attracted by this great success has brought letters of inquiry from the District of Columbia, from 109 cities in 33 states, in Canada, and in Porto Rico, and that a considerable number of these cities have sent delegations to see conditions for themselves.

It is my firm conviction that a genuine victory has been won, and that it reflects the utmost credit upon all who had a part in it. But I am also convinced that if it is to be the permanent victory that it can be, unremitting enforcement and willing cooperation of all concerned must be maintained. It would be relatively easy to slip back into the dark age from which we have but just emerged. And of all those who are concerned in this problem, those who represent the fuel industry as producers and as dealers are just as important as, perhaps more so than, those city officials who must guard the public interest. Producers and dealers alike have the obligation to live up to the old motto, "Noblesse Oblige," by sparing no effort to provide their customers with a product that can give no offense to civilized decency. Many of them have recognized that responsibility, and more are falling into line. There are products already on the market, and others about to come, which give ample ground for believing that a relatively cheap smokeless fuel made from Illinois coal will soon be available in ample quantity for those who must continue to use small hand-fired stoves and furnaces. This fact, in combination with the availability of small mechanically-operated equipment, assures ultimate victory if the administration of the law continues to be honest and in the public interest. The exigencies of national defense preparations may temporarily halt the development of a sufficient smokeless fuel supply, but here we must take the long view.

For 20 years I had the privilege of serving as a member of the City Plan Commission in my native city. That experience, reinforced by reading and study of the subject, plus personal observation in many other cities, convinced me that a permanent victory over the smoke nuisance will have a profound effect upon community life and upon property values. I would not say that smoke alone has been responsible for the wholesale abandonment of large urban areas, but I believe it to be one factor in the process of urban decay. What is more to the point, I believe that the elimination of smoke can easily be a prime factor in the restoration of blighted areas. I believe that the City of St. Louis has shown the way to the solution of an old and vexing problem. As a citizen, I take pride in the accomplishment, and my hat is off to the men whose zeal and ability made it possible.

XII. COAL ANALYSES AND THEIR RELATION TO COMBUSTION CHARACTERISTICS

J. L. G. WEYSSER*

The purpose of this paper is twofold: first, to summarize some of the more common kinds of analyses or analytical studies made of coal, as to both the fundamental principles involved and the kind of information revealed; and second, to discuss briefly the properties of certain constituents of coals (of the Eastern Interior Basin), from the standpoint of their effect upon the combustion characteristics of the fuel.

Nothing new is presented here. Rather, what is given is essentially a summarization, from an engineer's viewpoint, of some of the fundamental material included in standard textbooks and publications on the subject. Undoubtedly there are many who are entirely familiar with this material, and to them due apologies are made. In a sense, an object of this writing is to define terms; also, it is hoped that it may serve as a background for some of the other papers offered in this course. The subjects covered are the constitution, the ultimate analysis, the proximate analysis, the calorific value, the coking properties, some of the properties of the volatile constituents, and the ash of coal.

Constitution

Let us consider first the essential features of the formation, occurrence, and constitution of coal. These subjects are interrelated, and in turn together affect the methods of analysis.

Coal is of vegetable origin. During the coal-forming periods, a combination of ideal conditions—including a humid, equable climate, with an atmosphere containing considerable carbon dioxide, and virgin soil in a land mass of low elevation—led to the development of large swamp areas, and within these areas promoted a profuse growth of many types of plants, including several species of large trees. In turn, great quantities of vegetal material accumulated in beds made up of many layers of varying thickness and composition. And, of course, occasionally soil materials were mixed with some of the layers. But the process of accumulation was not continuous, because the elevation of the land mass fluctuated, and at times such an area would become completely inundated. During such intervals, clays and sands

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and again, sometimes vegetal matter, were transported to the body of water by streams and other agencies, and deposited as sediments. When the intervals were short, layers of what is now boney coal, or shaley partings in a coal seam, were formed; on the other example, whole series of rock strata, which now occur between separate coal seams, were laid down. Meanwhile, the vegetal material, which may be thought of as having had a general composition similar to that of cellulose ($C_6H_{10}O_5$), was subjected during the early phase to biochemical action, and subsequently, largely as a result of the pressure of superimposed sediments, to geochemical action. These activities converted it, by decreasing the relative proportions of the hydrogen, and more particularly the oxygen, through successive stages to peat, lignite, and the increasingly higher ranks of coal. After their formation, the coal beds were subjected to additional activity. In some instances earth pressures altered their structure, and the character of the coal. Cracks were formed; some of these were filled with clay forced in by pressure. Ground water deposited mineral substances, from solution, in other cracks and in porous layers of the coal.

Thus it is seen that coal is a non-uniform, heterogeneous substance. It is a natural, and hence haphazard, mixture of a variety of organic materials which have been subjected to varying degrees of alteration, with varying amounts of extraneous substances. Let us now consider an individual lump or specimen of Illinois coal. As would be expected from the foregoing discussion, it exhibits a banded structure. These bands are parallel to the bedding planes of the seams, and are of four varieties, and certain generalities may be made of them. The nomenclature adopted from that of Dr. M. C. Stopes by the Illinois State Geological Survey, and defined by Dr. G. H. Cady, will be used; on this basis the four varieties are designated as vitrain, clarain, durain, and fusain.

Vitrain is the brilliant, glassy-looking, jet black coal which occurs in bands from a fraction of an inch up to as much as two inches in thickness. It is more brittle than other ingredients of the coal bed, so that disproportionate amounts usually segregate in the fine sizes other than the very fine dust. However, it does not soil the hands. In a general way, it is homogeneous. Microscopic analysis reveals that it is usually derived from the woody parts of plants, such as branches and roots. Therefore it may be said that this material is usually uniform, and has a relatively low ash content, since all the ash substance in it must be only that which was originally in the plants.

Clarain is the coal that is relatively bright, but has a silky luster, and usually occurs in bands of variable thickness. It is composed of attritus—macerated spores, bark, etc.,—intermingled with fine strands of vitrain. The attrital material is predominantly translucent in thin section; this property, together with the fine strands of vitrain, is taken as the explanation of the silky appearance of clarain.

Durain is the name given to the dull bands of coal. It is black to lead gray in color, is much harder than the other varieties, and is composed of attrital material which is largely opaque. It may be said that the varieties of coal composed of attritus are usually of relatively higher ash content, as a result of admixture of mineral matter during deposition.

The fourth variety is designated as *fusain* or mineral charcoal. It usually occurs as paper thin bands or lenses, and is extremely friable, and hence is the principal component of the finest coal dust. While it is not very predominant on a coal face at right angles to the bedding, it is often seen on the bedding-plane surfaces of lumps, since breakage in this direction usually takes place along a band of fusain because of its weakness. Also, fusain layers are very porous; hence they frequently are found to be impregnated with mineral matter—calcite (calcium carbonate, $CaCO_3$), pyrite (iron sulphide, FeS_2), and others —deposited from circulating ground-water solutions as mentioned previously. Mineralized fusain is hard and, as may be expected, of high ash content.

In addition to the banded substances, occasional thin layers of calcite are found at right angles to the bedding plane, where this substance was deposited, from solution, in cracks or cleats.

The foregoing discussion has been included to emphasize and explain the fact that coal is of variable and indefinite composition, and therefore is not subject to chemical analysis in the way that a chemical compound is. Also, while coal from a given seam may have a certain average composition, the various gravity and size groups of the material from it may well be expected to differ in one or more important ways. However, a chemical analysis does reveal very useful information. These analyses are made on very small quantities, which obviously, therefore, require intelligent, careful sampling so that the material tested is representative of the whole, whether that is a coal seam, a certain size product, a shipment, or the like. The two common kinds of analyses are the *ultimate* and the *proximate* analysis. These will now be discussed.

Ultimate Analysis.—The ultimate analysis is distinctly a chemical analysis which is made to determine the amounts of the various

TABLE 1
COMPARATIVE COMPOSITION OF PEAT. AND COALS
(Adopted from Moore, E. S., "Coal," John Wiley & Sons)

	Total Moisture per cent	Total Ash per cent	Ultimate Analyses, Moisture- and Ash-Free				
			Carbon per cent	Hydrogen per cent	Oxygen per cent	Nitrogen per cent	Sulphur per cent
Peat	56.70	5.99	56.36	5.44	33.53	2.95	1.72
Lignite	34.55	7.20	72.79	4.74	19.60	0.98	1.89
Sub-bituminous	24.28	3.25	76.28	4.74	17.01	1.47	0.50
Bituminous	3.24	7.11	87.00	5.39	5.18	1.37	1.06
Bituminous (Low Volatile)	2.03	8.19	89.07	4.37	2.64	1.40	2.52
Semianthracite	3.38	11.50	92.15	3.76	2.17	1.18	0.74
Anthracite	2.80	7.83	94.39	1.77	2.13	0.71	1.00

elements in coal (namely: carbon, hydrogen, oxygen, nitrogen, and sulphur), without any distinction of the manner in which the elements occur. Thus the total percentage of carbon is found, but the relative proportions which occur in the coal as fixed-, or molecular carbon, or in hydro-carbon compounds, or in carbon-hydrogen-oxygen compounds, are not revealed. Of course, the total moisture and ash are also determined.

The principles of the analytical procedure are related to those involved in any quantitative analysis. A separate determination of the moisture content is made as described in the proximate analysis. Carbon and hydrogen are determined gravimetrically, by burning a small (usually 0.2 gram), accurately weighed sample of finely ground dry coal in a train of apparatus which passes the gases of combustion through a tube of hot copper oxide (to insure complete oxidation of the carbon and hydrogen to carbon dioxide and water vapor) and thence through other containers where these gases are absorbed by chemicals, and their weights determined by measuring the resulting weight increase. These weights are then converted by calculation to equivalent weights of carbon and hydrogen. The ash is determined by weighing that remaining from the completely burned sample. Separate analyses are made, by other quantitative methods, for nitrogen and sulphur, and sometimes for oxygen, although the latter is usually calculated by difference. Detailed explanations and descriptions are to be found in many references.

Table 1 shows an application of data from ultimate analyses of peat and typical coals of several ranks to the discussion on coal formation. The total moisture and ash percentages are given, but the percentages of the elements carbon, hydrogen, oxygen, and sulphur as listed are calculated to the moisture- and ash-free basis to permit better comparison. The relative increase of carbon, and decrease of hydrogen and oxygen, with increase in rank, are brought out.

An important application of ultimate-analysis data is that involved in calculations of the air required for combustion of a fuel. From the chemical equations for the burning of carbon, hydrogen, and sulphur, respectively, with oxygen, and with computation to allow for the relative molecular weights, and the proportion of oxygen in air, the following formula is developed:

$$\text{Weight of air per lb. of fuel} = 11.6C + 34.8\left(H - \frac{O}{8}\right) + 4.35S,$$

wherein C, H, O, and S are the percentages of these elements, expressed as fractional amounts.

It is also possible to calculate the heating value of a coal from its ultimate analysis, from the theoretical heating values of the several combustible substances. But the most interesting and useful application of this principle is the reverse process as set forth by the late Professor Parr. As may be gathered, the complete ultimate analysis is a lengthy process, and requires elaborate equipment. Hence, it is not extensively employed. However, at times the combustion engineer requires this kind of information; in these cases the "short ultimate" of Parr will usually meet all requirements.

Proximate Analysis.—The proximate analysis, in contrast to the ultimate, is really a physical rather than a chemical analysis. In this analysis, the amounts of moisture, volatile matter, fixed carbon (by difference), and ash are determined.

The principles involved in the procedure are quite simple. The methods and technique have been highly standardized, and are covered in detail in publications of the American Society for Testing Materials and of the United States Bureau of Mines. In a sense, the standards are empirical, but it will be recognized that they fit the definitions; moreover, results obtained are consistent.

Before reviewing the principles of the analysis, it would be well to consider the control of the moisture content of the sample, because the percentage of moisture in the coal from which the bulk sample is taken is an important factor. During the process of taking the bulk sample and reducing its size, and delivering it to a laboratory, precautions to prevent gain or loss in moisture must be observed. If the sample is to be shipped, an air-tight container should be used. Upon receipt in the laboratory, the entire sample is brought to a controlled moisture condition (as, for example, air-dried to equilibrium with the laboratory atmosphere), the moisture loss being measured by weight. The sample is then ground and reduced in bulk in successive steps until a working laboratory sample of perhaps 60 grams of fine (—60-mesh) coal is obtained; this is kept in a rubber-stoppered bottle. Now, since the difference between the moisture content of the original, or "as-received" sample, and that of the laboratory sample is known, it is possible to convert the data from analysis of the laboratory sample to the as-received basis by calculation. Detailed standards of procedure in sampling are given in the publications mentioned.

The moisture content of the laboratory sample is determined by heating 1.0000 gram of the coal, in a small open container, in a moisture oven for one hour at 105 deg. C. (221 deg. F.), and measuring the loss in weight. The amount of volatile matter is determined by heating another 1.0000 gram portion of the laboratory sample, in a covered platinum crucible, in a special electric furnace exactly 7 minutes at 950 deg. C. ($\pm$ 20 deg. C.) (1742 $\pm$ 36 deg. F.), measuring the weight loss, and deducting the weight of moisture in one gram of coal as previously determined. The ash is determined by heating the residue from the moisture determination in a porcelain crucible. It is heated slowly at first, to drive off the volatile, and finally burned to constant weight in a muffle furnace at 750 deg. C. (1382 deg. F.). Fixed carbon is calculated by subtracting the sum of the percentages of moisture, volatile matter, and ash from 100 per cent.

The data from the laboratory sample are then converted to the as-received state by multiplying each percentage by (100 — moisture lost on air drying), and dividing by 100. To the moisture percentage thus obtained is added the loss on air drying; this yields the total moisture, which, with the other figures, should of course total 100 per cent.

The proximate analysis provides considerable, and very useful, information. The effects of moisture and ash in contributing useless weight to the coal, and in consuming and hence nullifying part of its heating value, are well recognized. The percentage of fixed carbon is a measure of the amount of coke that will be produced, assuming a coking coal. (Of course, all of the ash will be in the coke.) Also, the character of the residue from the volatile matter determination indicates the coking property of the coal. In fact, the American Society for Testing Materials standard to determine whether or not a coal is agglomerating consists simply of a measure of the strength of the coke button produced. Furthermore, the appearance and size of the button

TABLE 2
PROXIMATE ANALYSES OF PEAT AND COALS
(Adopted from Moore, E. S., "Coal," John Wiley & Sons)

	As-Received				On a Moisture- and Ash-Free Basis	
	Moisture per cent	Volatile Matter per cent	Fixed Carbon per cent	Ash per cent	Volatile Matter per cent	Fixed Carbon per cent
Peat	56.70	26.14	11.17	5.99	70.06	29.94
Lignite	34.55	35.34	22.91	7.20	60.67	39.33
Sub-bituminous	24.28	27.63	44.84	3.25	38.12	61.88
Bituminous	3.24	27.13	62.52	7.11	30.26	69.74
Bituminous (Low Volatile)	2.03	14.47	75.31	8.19	16.12	83.88
Semianthracite	3.38	8.47	76.65	11.50	9.95	90.05
Anthracite	2.80	1.16	88.21	7.83	1.29	98.71

show the swelling properties, if any, although coals that give well-coked residues do not always produce good coke commercially. The relationship between the data provided by the proximate analysis and the combustion characteristics of coals will be apparent from study of the data given in Table 2, which gives the proximate analyses of the same coals listed in Table 1. The variations of moisture, volatile matter, and fixed carbon with the rank of the coals are indicated clearly. The effects of these various proportions may be brought out simply by a résumé of the burning characteristics of the higher rank coals. Anthracite, because it is dense and is composed almost entirely of fixed carbon, ignites slowly, and burns at a high temperature, with a very short flame and very little smoke. Semianthracite ignites more readily because of its higher hydrocarbon content. The burning properties of low volatile bituminous coal are, as is its rank, between those of semianthracite and the lower rank coals.

In addition to the proximate analysis, a determination of the heating value is made, and an analysis for the sulphur content of the coal (usually from the products of the calorimetric test) is carried out. These data—the proximate analysis, the heating value, and the percentage of sulphur—usually provide all the analytical information required.

Heating Value.—The unit of measure of heat usually used is the British thermal unit (B.t.u.), which is defined as the amount of heat required to raise one pound of water from 39.1° F. to 40.1° F. Heating value of coal is expressed in B.t.u. per pound of coal.

This is determined by means of a calorimeter; several types are in common use. The essential parts are a bomb, a water container,

TABLE 3
COMPARATIVE HEATING VALUES OF PEAT AND COALS
(Adopted from Moore, E. S., "Coal," John Wiley & Sons)

	Calorific Values, B.t.u. per Pound	
	On Moisture- and Ash-Free Basis	On As-Received Basis
Peat	9 609	3 586
Lignite	12 172	7 090
Sub-bituminous	12 938	9 376
Bituminous	15 527	13 919
Bituminous (Low-Volatile)	15 683	14 081
Semianthracite	15 457	13 156
Anthracite	14 882	13 298

and an insulating jacket. The bomb is arranged to provide an excess of oxygen—in the form of either compressed gaseous oxygen, or sodium peroxide, an oxidizing chemical—to insure complete and rapid combustion of a small sample of coal. The charged bomb is placed in the jacketed container, into which a definite quantity of water has been poured. The charge in the bomb is then fired. Readings of the water temperature are taken at intervals over a period before and after firing; from these, and with various correction computations, the calorific value of the fuel is calculated.

Since the combustible elements in coal are carbon, hydrogen, and sulphur, it follows from the data in Table 1 that the heating value of coals increases with the rank. This is illustrated by the range of the values of the coals listed in the tables (see Table 3): on the moisture- and ash-free basis, the value for the peat is 9609 B.t.u. per pound, and these values range upward to 14 882 for the anthracite. Also, the effect of moisture and ash has been mentioned; this is emphasized by the corresponding calorific values of these same coals on the as-received basis. The range in this case is from 3586 B.t.u. per pound for the peat up to 13 298 for the anthracite.

If the determination is made with a Parr sodium peroxide calorimeter, all of the carbon of the coal sample enters into the formation of sodium carbonate—a fused solid which remains in the bomb. This product can be conveniently analyzed for the carbon, and thus the total carbon content of the coal is disclosed. Then, from the known theoretical heating values of carbon, hydrogen, and sulphur, and with knowledge of the heating value of the coal and its carbon and sulphur content, the calculation of the approximate ultimate analysis alluded to is made possible.

Coking Properties.—The coking properties of bituminous coals have an important effect upon their use in certain ways. The difficulties engendered by the formation of coke-trees in domestic stokers are an example. The formation of coke takes place because the coal contains a substance which has a definite melting point. With reference to the earlier discussion of the constitution of coal, it may be said that the conversion processes in some instances completely eliminated the cellulose, and have produced a material which is bituminic in character. This applies particularly to most of the material identified as vitrain.

In a general way, it may be said that Illinois coals are not strongly coking, and hence do not offer too much difficulty. In the use of coals which tend to form strongly swelling coke in domestic stokers, it is believed that much can be accomplished by careful regulation of the draft and firing periods.

Volatile Matter.—In the discussion of the formation of coal, it was stated that certain activities broke down the original carbon-hydrogen-oxygen compounds. In this process, considerable quantities of oxides of carbon and hydrogen, and of hydrocarbons, were produced. Some of these escaped, but much of these materials remained associated with the coal as what is called the volatile matter. The association of smoke with the burning of high volatile bituminous coals is perhaps too well known, and not understood. Unsuitable equipment and improper firing methods aggravate the situation. The late Professor Parr has stated the principles nicely, and his words are quoted:

The showing of large volumes of smoke is a sure sign of serious loss of the fuel constituents. The underlying principles furnish a sufficient explanation for the losses which accompany heavy smoke. A brief enumeration is here given:

(a) At temperatures below 750 deg. F. about one-half of the total volatile matter of bituminous coal is discharged.

(b) The first distillates at these lower temperatures are composed of water vapor, oxides of carbon, some hydrogen and methane, but chiefly the so-called heavy hydrocarbons, ethylene, propylene, benzene, etc., including also some compounds which are light oils and tars at ordinary temperature.

(c) Under the most favorable conditions it is difficult to burn these heavier compounds without producing a smoky flame, a prerequisite being a much larger mixture of air than that required for the distillates which come off at the higher temperatures, mainly methane (CH_4) and hydrogen.

(d) A high percentage of moisture, which is also discharged simultaneously with the heavy hydrocarbons, accentuates the difficulty by sudden expansion into steam and consequent displacement of air, as well as by lowering the temperature of the combustion chamber while the process of vaporization is proceeding.

From this enumeration it is evident that to discharge these first distillates into a relatively cooler zone emphasizes the unfavorable conditions for combustion, and results also in a condensation of some of the compounds, all of which is made evident by the appearance of dense volumes of smoke.

It has been shown, in the discussion of the ultimate analysis, that the amount of air theoretically required per pound of coal may be calculated. Again quoting Professor Parr,

For any reasonable degree of efficiency under the conditions prevailing in the average combustion device, this amount of air must be increased by at least 50 per cent. Very much depends, however, upon the distribution of air allowance. The volatile hydrocarbons, which are discharged from the fuel bed, are at a double disadvantage. Not only are they particular in the matter of temperature at which they will maintain combustion and the ready accessibility of their oxygen supply, but they are further handicapped by the fact that this oxygen supply is haphazard in amount and not easily adjusted to meet the varying requirements of the volatile matter. This is the more readily appreciated when it is remembered that any combustion processes taking place in the combustion chamber above the fuel bed must come from openings above the gates, since practically no air with free or unused oxygen can come through the fuel bed.

It is evident from the preceding discussion that smoke reduction depends upon (a) admission of air above the fuel bed, (b) thorough mixing, and (c) the maintenance of a temperature above the ignition point of the gases and vapors involved. Failure on the part of any one of these three conditions will result in smoke where bituminous coal is being burned.

Ash.—Aside from the quantity of ash, its fusion temperature is the most important consideration. To determine this temperature in the laboratory, the ash from a coal is finely ground and molded into small triangular pyramids. These are placed in a special furnace and heated until they soften and lose shape. The temperature at which this occurs is measured.

The ash substance usually consists principally of the oxides of silicon, aluminum, iron, calcium, and magnesium, with small amounts of other compounds. Each of these substances has a definite melting temperature. However, mixtures melt at different temperatures, and sometimes eutectics—a mixture of compounds, in which the melting point is lower than that of any of the constituents—are formed. Pyrite, with its relatively low melting temperature, promotes clinker, and is especially troublesome because it tends to decompose with heat from FeS_2 to FeS; the FeS has an equally low fusion point, and is fairly stable chemically.

From the discussion of constitution, it follows that the composition of the ash of different sizes of the "same" coal may vary. For this reason, clinker formation properties are sometimes wrongly ascribed to the size of the coal, as being a function of the particle size per se.

XIII. BURNING ILLINOIS COAL SMOKELESSLY IN HAND-FIRED HEATING PLANTS

J. R. FELLOWS* and J. C. MILES†

Introduction.—It is an interesting paradox that both coal gas and carbon in their separate states are satisfactory fuels and, as such, enjoy the enthusiastic endorsement of the most critical smoke- abatement officials. However, when combined in the form of bituminous coal and fired by hand in conventional equipment, the gas causes unsatisfactory operation and produces objectionable smoke. This is due to no fault of the coal, but solely to lack of proper equipment for burning it. The essentials for smokeless combustion of high-volatile coal are

(1) Sufficient secondary air to burn all the gases completely
(2) Thorough mixing of air and gases
(3) Ignition temperatures must be maintained.

This paper shows the improved performance that results from reasonable adherence to these essentials when firing bituminous coal. It also shows that these essential conditions can be easily complied with by application of the down-draft principle of firing.

A conventional up-draft furnace was converted to the down-draft principle by installing a "down-draft burner" which is essentially a coking chamber that may be installed in any furnace.

Test results from firing the furnace by the up-draft and also by the down-draft method through use of a down-draft burner, show that high-volatile coal is essentially smokeless when fired by the latter method and is in some respects a more satisfactory fuel for hand firing than coke or other smokeless fuels.

Object.—The object of these investigations was to study the performance of a hand-fired furnace both with and without a down-draft burner, and when burning each of a variety of fuels under five different rates of burning.

Scope.—Investigations were made to determine the effect of several variables on furnace performance.

(1) A series of tests was made to determine the effect of coal size and preparation on the performance of a burner-equipped furnace.

(2) A series of tests was made comparing the performance of

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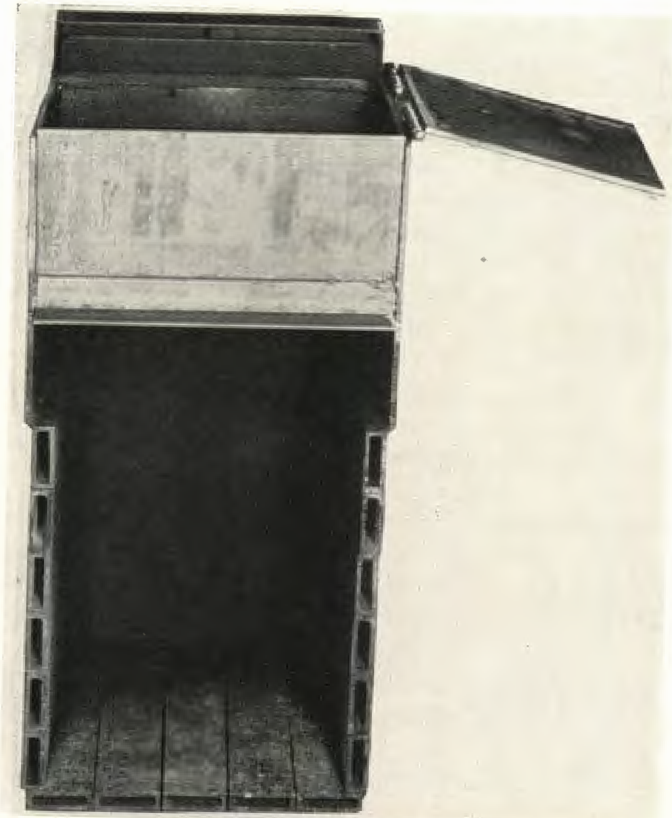

FIG. 1. DOWN-DRAFT BURNER—BOTTOM VIEW

Illinois coal fired in a burner-equipped furnace with "smokeless" fuels fired in a conventional furnace.

(3) A series of tests was made using low-volatile coal in a furnace (a) with the burner and (b) without the burner.

(4) A series of tests was made using Illinois coal in a furnace (a) with the burner and (b) without the burner.

Acknowledgments.—This investigation was a project of the University of Illinois Engineering Experiment Station, of which DEAN M. L. ENGER is the Director. The work was carried on in the Mechanical Engineering division of the Station, of which PROFESSOR A. P. KRATZ is the head.

Description of Down-draft Burner.—Figure 1 is from a photograph

FIG. 2. DOWN-DRAFT BURNER BEING INSTALLED IN FURNACE

of the down-draft burner used in these tests. The burner consists of a box-shaped container having a double-walled roof and sides through which secondary air is drawn into the furnace. The burner is installed in any conventional furnace by placing the open side down and shoving it in the firing door until it extends well into the combustion chamber, no alterations to the furnace being necessary. The burner is filled with coal through the firing door on the end. Air entering between the double roof leaves the burner at the bottom edge of the walls. The bottom edges of the walls are made of heat resisting alloy. The side walls and top are of fire-box steel.

Figure 2 shows a burner being installed in the test furnace. It may be noted that it is not essential that a burner closely fit the doorway of a furnace since the space between the burner and the firing neck of the furnace may be sealed with rock wool or other suitable material.

Figure 3 is a vertical cross-section of the test furnace with the burner in place, and shows the relative position of the green coal and the coke immediately after firing. Air entering at *A* supports combustion in the coke on the furnace grate as in any conventional

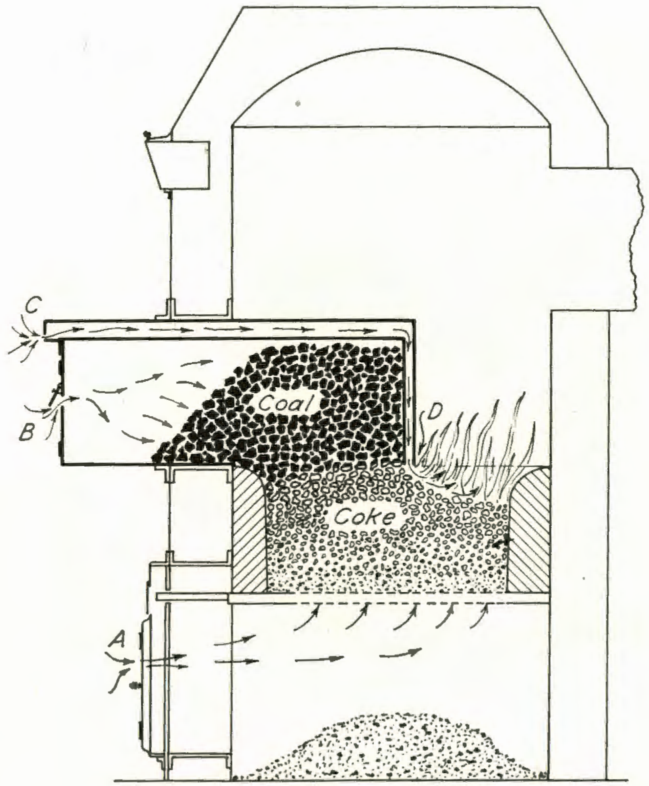

FIG. 3. VERTICAL CROSS-SECTION OF TEST FURNACE WITH DOWN-DRAFT BURNER IN PLACE

furnace. Air entering at *B* passes down through the green coal and supports slow combustion at the ignition plane. The rate of travel of the ignition plane up through the green coal and the consequent rate of coking is proportional to the rate at which air enters at *B*. The rate of coking is therefore controlled by the air inlet damper at *B*. Secondary air entering at *C* flows through the passage in the roof of the burner, which connects with vertical passages in the walls. This air emerges from the walls at *D* where it mixes with the volatile gases as they are drawn under the burner walls by the natural draft of the chimney. The burner side walls which extend into the furnace are provided with air passages like those in the rear wall, as may be seen by reference to Fig. 1.

The horizontal air passage in the roof and the vertical passages in

TABLE 1

SMOKE COMPARISON TESTS; HOLD FIRE OPERATION

24 Pounds of Coal Fired Every 24 Hours

Test No.	Fuel Burned	Max. CO_2 per cent	Av. CO_2 per cent	Max. Flue Gas Temp. deg. F.	Av. Flue Gas Temp. deg. F.	Max. Smoke Dens. per cent	Av. Smoke Dens. per cent	Max. Ringel. No.	No. Min. at Max. Ringel. No.
	Tests With Burner								
30	Ill. ¾ x 1/10	9.0	2.61	230	131	18.3	0.7	0.5	1
27	Ill. ¾ x 1½	9.7	2.95	315	145	12.1	0.1	0.5	1
28	Ill. 2 x 3	5.0	2.66	197	126	22.8	0.9	1.0	1
5	Ill. Fur. Lump	6.0	2.40	221	...	6.4	1.0	0.0	..
29	Ill. 3 x 1/10	6.9	2.19	225	127	22.7	0.8	1.0	1
51	West Va. 1 x 2	8.2	2.36	287	156	4.3	0.4	0.0	..
	Tests Without Burner								
59	West Va. 1 x 2	3.4	1.79	225	150	25.5	1.3	1.0	23

the walls are designed to distribute the secondary air in essentially a uniform sheet around three sides of the burner. The coke which is burned in the lower part of the furnace fire pot provides the incandescent surface necessary for igniting the mixture of air and volatile gases coming from the burner.

TABLE 2

SMOKE COMPARISON TESTS; MILD WEATHER OPERATION

25 Pounds of Coal Fired at 8:00 a.m. and 8:00 p.m.

Test No.	Fuel Burned	Max. CO_2 per cent	Av. CO_2 per cent	Max. Flue Gas Temp. deg. F.	Av. Flue Gas Temp. deg. F.	Max. Smoke Dens. per cent	Av. Smoke Dens. per cent	Max. Ringel. No.	No. Min. at Max. Ringel. No.
	Tests With Burner								
12	Ill. ¾ x 1/10	8.7	3.78	409	157	5.1	0.6	0.0	..
10	Ill. ¾ x 1½	8.0	3.76	220	141	6.7	0.7	0.0	..
11	Ill. 2 x 3	10.4	4.27	292	159	14.3	0.7	0.5	1
14	Ill. Fur. Lump	9.0	4.07	305	164	37.7	0.5	1.5	1
52	Ill. 3 x 1/10	9.2	3.29	314	164	9.2	0.4	0.0	..
42	West Va. 1 x 2	10.0	5.05	342	183	4.3	0.1	0.0	..
	Tests Without Burner								
26	Ill. 2 x 3	6.3	3.51	265	160	53.1	5.4	2.5	15
25	Ill. Fur. Lump	5.5	4.38	195	177	23.5	3.2	1.0	11
23	West Va. 1 x 2	3.8	2.83	184	149	11.0	1.1	0.5	9
22	Coke	8.0	4.30	362	199	17.1	0.6	0.5	1
24	Ark. Anth.	3.4	2.56	148	143	6.3	0.6	0.0	..

TABLE 3

SMOKE COMPARISON TESTS; AVERAGE WINTER OPERATION

35 Pounds of Coal Fired at 7:00 a.m., 12:00 m., 5:00 p.m., and 10:00 p.m.

Test No.	Fuel Burned	Max. CO_2 per cent	Av. CO_2 per cent	Max. Flue Gas Temp. deg. F.	Av. Flue Gas Temp. deg. F.	Max. Smoke Dens. per cent	Av. Smoke Dens. per cent	Max. Ringel. No.	No. Min. at Max. Ringel. No.
	Tests With Burner								
48	Ill. ¾ x 1/10	12.6	7.65	380	252	28.0	0.9	1.0	1
45	Ill. ¾ x 1½	14.1	7.30	446	255	20.0	0.6	1.0	1
47	Ill. 2 x 3	14.9	7.97	400	254	26.0	1.2	1.0	1
53	Ill. Fur. Lump	10.2	8.51	310	249	9.7	0.6	0.5	1
40	Ill. 3 x 1/10	15.3	8.22	400	240	6.8	1.1	0.0	. .
49	West Va. 1 x 2	13.0	8.68	438	266	15.6	0.1	0.5	1
	Tests Without Burner								
56	Ill. 2 x 3	12.7	6.91	440	253	40.0	5.6	2.0	30
55	Ill. Fur. Lump	9.0	4.89	350	230	21.0	3.2	1.0	22
54	West Va. 1 x 2	15.2	5.59	350	257	28.0	1.7	1.0	10
43	Coke	7.8	6.01	334	214	4.1	0.6	0.0	. .
44	Ark. Anth.	6.0	4.03	403	218	2.1	0.3	0.0	. .

Arrangement of Test Apparatus.—A conventional refractory-lined steel furnace was used having a 21-in. grate, and fitted with a crescent-type radiator. Draft was obtained from a steel stack 12 inches in

TABLE 4

SMOKE COMPARISON TESTS; COLD WEATHER OPERATION

50 Pounds of Coal Fired at 7:00 a.m., 12:00 m., 5:00 p.m., and 10:00 p.m.

Test No.	Fuel Burned	Max. CO_2 per cent	Av. CO_2 per cent	Max. Flue Gas Temp. deg. F.	Av. Flue Gas Temp. deg. F.	Max. Smoke Dens. per cent	Av. Smoke Dens. per cent	Max. Ringel. No.	No. Min. at Max. Ringel. No.
	Tests With Burner								
2	Ill. ¾ x 1/10	14.0	10.83	364	253	9.0	0.7	0.0	. .
1	Ill. ¾ x 1½	15.6	11.98	350	291	17.5	0.8	0.5	1
3	Ill. 2 x 3	14.8	10.11	357	298	16.0	1.1	0.5	1
4	Ill. Fur. Lump	15.1	10.67	385	306	23.0	1.5	1.0	5
39	Ill. 3 x 1/10	15.0	11.49	450	264	20.0	1.1	1.0	8
41	West Va. 1 x 2	13.0	10.42	376	259	6.1	0.3	0.0	. .
	Tests Without Burner								
8	Ill. 2 x 3	15.1	9.94	527	296	82.0	9.4	4.0	65
9	Ill. Fur. Lump	15.4	9.44	450	311	65.0	6.6	3.0	11
6	West Va. 1 x 2	11.4	7.48	291	259	27.2	1.5	1.0	5
7	Coke	17.0	9.76	476	335	8.1	0.5	0.0	. .
35	Ark. Anth.	11.0	8.41	495	276	2.8	1.0	0.0	. .

TABLE 5

SMOKE COMPARISON TESTS; EXTREME COLD WEATHER OPERATION

45 Pounds of Coal Fired Every 3 Hours

Test No.	Fuel Burned	Max. CO_2 per cent	Av. CO_2 per cent	Max. Flue Gas Temp. deg. F.	Av. Flue Gas Temp. deg. F.	Max. Smoke Dens. per cent	Av. Smoke Dens. per cent	Max. Ringel. No.	No. Min. at Max. Ringel. No.
	Tests With Burner								
18	Ill. ¾ x 1/10	15.3	12.68	560	386	3.8	1.1	0.0	. .
17	Ill. ¾ x 1½	16.6	13.18	423	380	14.0	2.1	0.5	1
16	Ill. 2 x 3	15.3	12.73	370	340	28.0	3.7	1.0	5
15	Ill. Fur. Lump	14.9	12.09	490	410	5.0	1.1	0.0	. .
38	Ill. 3 x 1/10	16.0	14.45	436	394	15.0	2.8	0.5	6
50	West Va. 1 x 2	13.4	12.92	351	344	2.4	0.3	0.0	. .
	Tests Without Burner								
36	Ill. 2 x 3	13.8	5.89	680	448	61.0	11.1	3.0	21
37	Ill. Fur. Lump	9.6	4.52	540	395	35.0	7.2	1.5	6
20	West Va. 1 x 2	13.2	7.12	551	429	16.0	2.0	0.5	15
19	Coke	13.3	9.59	619	448	0.9	0.02	0.0	. .
21	Ark. Anth.	13.8	9.89	683	489	2.5	0.2	0.0	. .

diameter and approximately 30 feet in height. Draft was controlled by a barometric-type draft regulator.

A recording meter was used to make a continuous record of the CO_2 and a standard Orsat apparatus was used for periodically checking the CO_2 recorder. Smoke density was measured by an indicating and recording meter consisting of a light source, a thermopile, and a recording potentiometer. Flue gas temperature was measured in the smoke pipe three feet from the smoke collar, and recorded by a conventional gas-filled thermometer.

Test Procedure.—A variety of fuel types and preparations, as listed in Tables 1 to 5, inclusive, were fired in the test furnace, both with and without the use of a down-draft burner. Each fuel preparation was burned under conditions simulating those encountered during a complete heating season, namely, hold fire, mild weather, average winter weather, cold weather, and extreme cold weather, for which burning rates of approximately one, two, six, eight, and fifteen pounds per hour were used. Each test was 24 hours long, with the exception of those in which the fuel was burned at the maximum rate.

Before starting a test a typical fuel bed was established from the type of fuel to be tested. Before placing coal in the burner, the coke remaining from the previous charge was pushed into the fire pot of

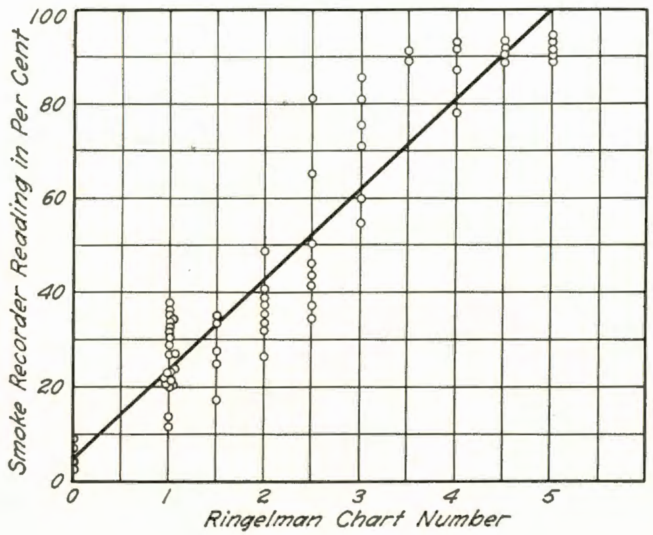

FIG. 4. SMOKE DENSITIES

the furnace. The fire was not disturbed after starting any test except at refiring, as shown in Tables 1 to 5. When firing without the burner, any residual coke was pushed to one side of the fire pot, and the green fuel placed on the other, except in the cases of coke and anthracite, which were placed directly over the remaining coals. In all tests, on placing a new charge, the grates were shaken as much as was necessary to obtain the desired combustion rate.

The combustion rate was controlled in the burner-equipped furnace by a conventional check damper in the smoke pipe and a damper controlling the amount of primary air entering the front of the burner. For tests without the burner the conventional check damper in the smoke pipe and the ash pit air damper were used. The ash pit door and the ash pit air damper were kept closed throughout all tests with the burner, for sufficient air leaked into the ash pit to burn all coke in the fire pot completely. No adjustments were made in the secondary air during any test.

Fuel was fired every three hours in the tests simulating extreme cold weather, four times per day in the tests simulating cold and average winter weather, two times per day in the tests simulating mild weather, and once a day in the hold-fire tests. Hold-fire tests were not conducted when the furnace was used without the burner, for the

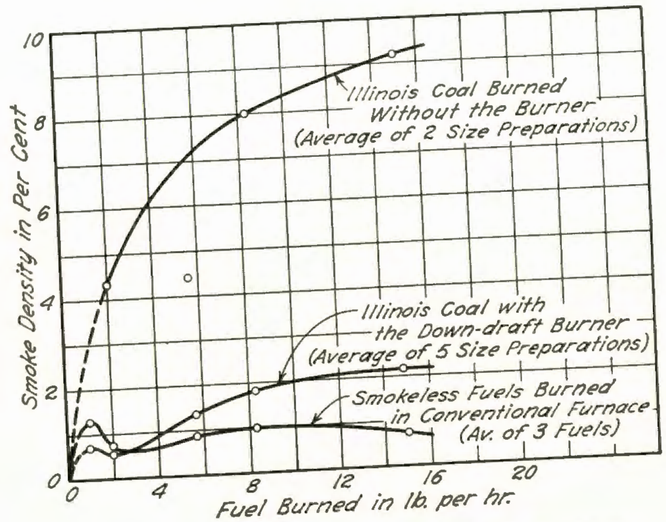

FIG. 5. AVERAGE SMOKE DENSITIES FROM ALL TESTS

fire would not last for more than twelve hours except in the case of West Virginia coal.

The smoke density meter was calibrated in terms of Ringelmann numbers by observing the stack against the sky. For the convenience of readers who are familiar with the Ringelmann chart, Fig. 4 was prepared by plotting smoke densities as measured by the recorder against observed Ringelmann numbers. The wide spread of the points indicates the limitations of the human eye in judging the exact density of smoke. It is the opinion of the authors that a smoke density recorder of the type used in these tests provides a far more dependable and accurate method of measuring smoke density than judging the density of the smoke as it leaves the top of a chimney. It may be noted that for recorder readings as high as 9 per cent, no smoke was detected by the observer watching the stack, thus indicating a degree of sensitivity beyond that of the human eye.

Discussion of Results.—Tables 1 to 5, inclusive, present a summary of all data collected. The maximum CO_2, maximum flue gas temperature, and maximum smoke density were read directly from the charts, while the average values were determined by averaging the hourly readings for each test. The Ringelmann numbers recorded were obtained by using the graph shown in Fig. 4. The numbers were read from the graph to the nearest five-tenths. Since the duration of a smoking period is just as important as the maximum smoke density,

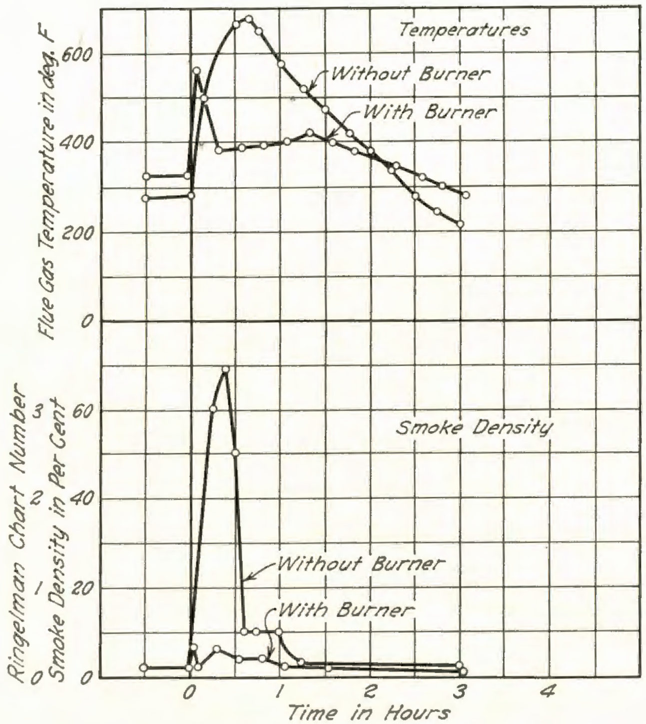

FIG. 6. SMOKE DENSITIES AND FLUE GAS TEMPERATURES WITH AND WITHOUT DOWN-DRAFT BURNER

the number of minutes during which the given smoke density persisted is recorded in the right-hand column of each table.

Smoke.—While a smoke density equivalent to a number 1 Ringelmann chart occurred during a few tests with the burner, it may be pointed out that the time during which the smoke persisted was negligible in nearly every case. The greatest tendency to smoke occurred during tests simulating cold weather operation in which fifty pounds of coal were fired every five hours except at night, and the fire was checked the greater part of the time. On some occasions the fuel in the burner was not completely coked when it was pushed into the furnace fire pot, thus causing a tendency to smoke. However, at no time was it sufficient to constitute a violation of any smoke ordinance.

Figure 5 shows a general summary of the average smoke densities from all tests. It may be noted from the curves that the smoke produced from burning Illinois coal with the burner was practically

negligible under all conditions of operation, and exceeded only slightly that produced by firing "smokeless fuels" in the conventional updraft furnace.

Heat Release.—Figure 6 shows the action of a fire in a conventional furnace with and without the burner during cold weather operation. It may be noted that the smoke density was negligible when the burner was used. Instant response of the fire is indicated by the fact that the flue gas temperature reached a maximum while the coal was being fired. The curve representing flue gas temperatures shows that the burner definitely limits the combustion rate and there is no danger of overheating the furnace. Thus a more even heat release is obtained from a burner-equipped furnace, and it is much easier to maintain an even house temperature. The maximum heat delivery rate is slightly less with a burner-equipped furnace, but actual installation tests over a period of five years indicate that burner-equipped furnaces will amply meet peak demands occasioned by extreme cold weather. A burner may be filled with coal at night and the dampers set to produce steady burning, so that the house temperature does not drop as much as when a furnace is used without the burner, and therefore it is not necessary to have so hot a fire for warming the house in the morning.

Conventional Furnace Operation in Mild Weather.—In the average home when little heat is required during mild weather the fire is usually neglected until the fuel bed has burned very low. Application of the side bank method of firing results in the green coal failing to ignite, so instead, a small charge is placed directly over the few remaining coals. This results in a smoldering fire in which none of the volatile gases are burned until sufficient heat is generated in the fuel bed to ignite the gases at some point and produce a flame. Considerable time may elapse before a flame is produced. This action is illustrated by Fig. 7, which shows the smoke density for Illinois coal fired in this manner. It may be noted that the smoke density was low for the period immediately following the placing of the 25-lb. charge, because there was not sufficient heat in the fuel bed to drive off the volatile gases at a high rate. Although none of the volatile gases were burned, they were so diluted with excess air that the smoke density was not high. The gradually increasing temperature below the green coal produced a gradual increase in the smoke density until it reached a maximum of 53 per cent two and one-quarter hours after placing the charge. At that time, gas at some point in the fuel bed ignited and the resulting flame spread over the fuel bed, causing the

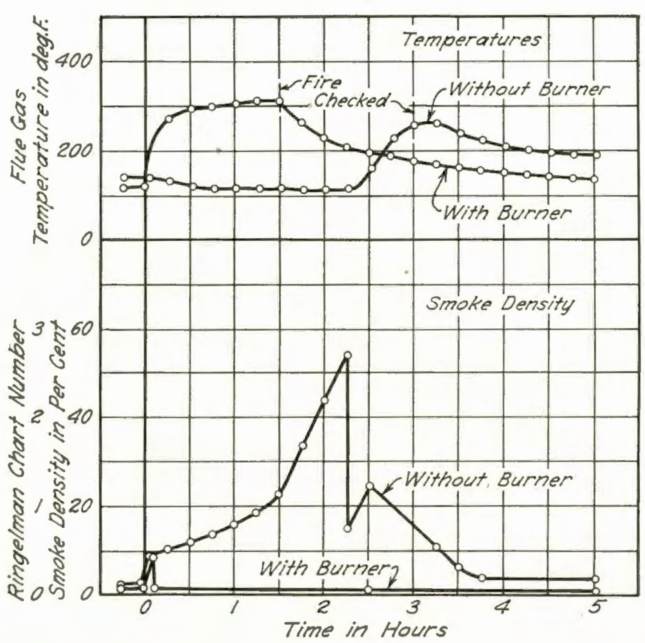

FIG. 7. SMOKE DENSITIES AND FLUE GAS TEMPERATURES WITH AND WITHOUT DOWN-DRAFT BURNER—MILD WEATHER

smoke density to decrease sharply to 14 per cent. The increased heat release from this gas flame further accelerated distillation, causing a slight deficiency of secondary air and a corresponding second increase in smoke density. After fifteen minutes, however, the smoke cleared because practically all of the volatile had been distilled by that time. The smoke density curve of Fig. 7 explains the smoke palls from "soft" coal fires which occur when cool evenings follow comparatively warm days.

Down-draft Operation in Mild Weather.—Figure 7 also shows the action of a fire in a burner-equipped furnace under the same conditions. Although the fuel bed temperature was lower when the burner was fired than in the preceding case, the coals in the burner quickly reached a high temperature, as indicated by the flue gas temperature, for the air entering through the doorway and passing through the coke in the burner greatly accelerated the combustion rate in the coke and rapidly increased the fuel bed temperature, with the result that when the coal was fired the fuel bed temperature was

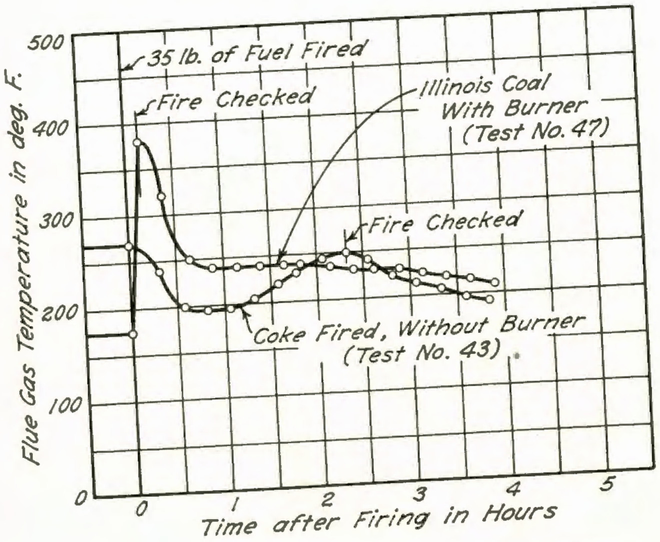

FIG. 8. FLUE GAS TEMPERATURES AFTER FIRING

high enough to ignite the volatile gases immediately, and practically no smoke was produced. Heat was delivered from the burner-equipped furnace immediately after it was fired in contrast to the conventional furnace in which the fire smoldered for two and one-quarter hours.

Coke Firing.—Coke fired in the conventional furnace without the burner was practically smokeless at all times, but was very slow to respond, even though the fuel bed was in good condition when the furnace was fired, as shown in Fig. 8. The fuel bed was hot when the charge was fired, and the dampers were set for maximum heat delivery, but the flue gas temperature decreased for more than one-half hour after the charge was placed. This was due to covering the fire with a layer of cold coke. Using Illinois coal under similar conditions with the burner, the flue gas temperature increased to 360 deg. F. during the five-minute process of firing, and the furnace was ready to check as soon as the coal had been placed. The flue gas temperature then remained practically constant for the next three hours, thus indicating a uniform combustion rate and heat delivery. The coke fire would have responded more quickly if the grates had been shaken to decrease the thickness of the ash layer below the fuel bed, but the ash layer was found to be necessary to prevent a higher average combustion rate than was desired. In cold weather operation with coke the grates were

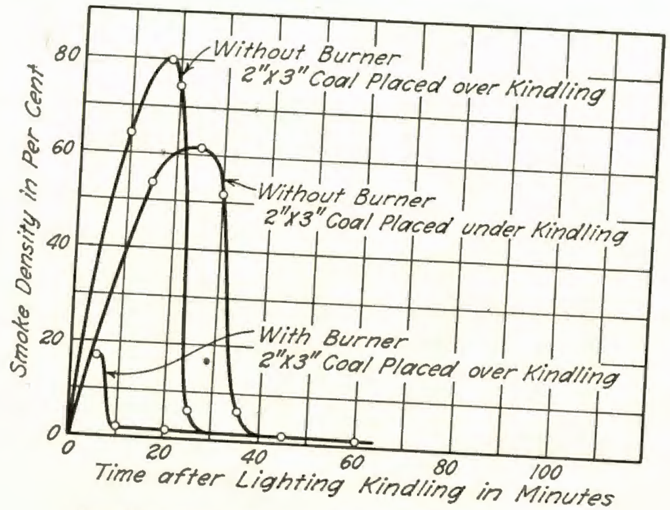

FIG. 9. SMOKE DENSITIES PRODUCED IN STARTING FIRE

vigorously shaken before placing a charge, and the fire responded in a reasonably short time, but the combustion rate soon reached dangerous proportions if not checked.

Starting Fires.—Figure 9 shows the smoke produced in starting a fire. Two starting tests were made in the conventional furnace without the burner, one in which the coal was placed over the burning kindling, and one in which the coal was first placed in the furnace and the kindling fire built on the coal. It may be noted that a smoke density of 80 per cent, corresponding to a Ringelmann number of 4, was produced when the coal was placed on top of the kindling. The maximum smoke density was considerably lower when the kindling fire was built on top of the coal, but the smoke persisted for a somewhat longer period.

The smoke produced in starting a fire in a burner-equipped furnace was negligible compared with that produced by either of the foregoing methods. The kindling placed just below the burner provided the necessary ignition surface for volatile gases coming from the coal in the burner, and the gases were forced to pass directly over the kindling, with the result that very little smoke was produced.

Low Volatile Fuels.—Figure 10 shows a summary of the average CO_2 and smoke densities resulting from burning low volatile West Virginia coal with and without the burner. As may be seen, a much higher average CO_2 was obtained in the burner-equipped furnace.

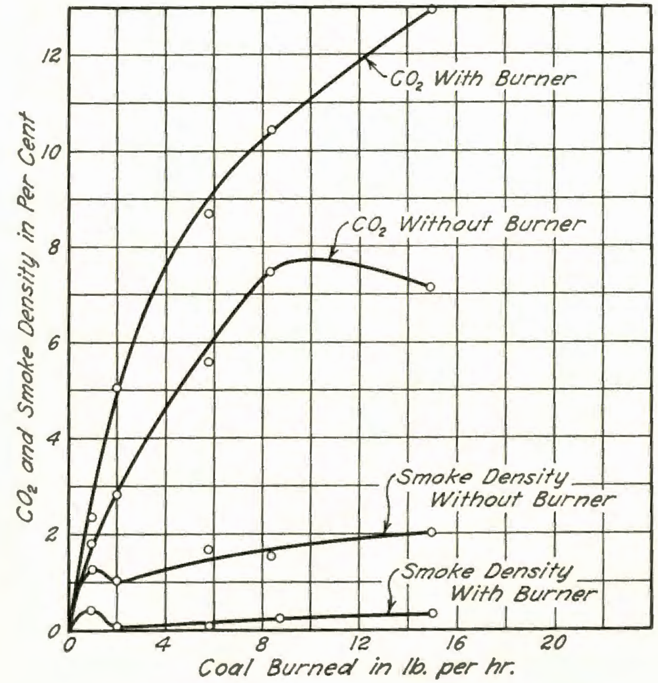

FIG. 10. AVERAGE SMOKE DENSITY AND CO_2 WITH AND WITHOUT DOWN-DRAFT BURNER

The smoke produced by this fuel is low regardless of how it is burned, but it is seen to decrease still further when fired in a burner-equipped furnace.

It was found that even the low volatile coal produced a smoldering fire when fired without the burner if the fuel bed temperature was low when fired. The first point on the curve of Fig. 10 representing smoke density for tests without the burner is higher than the rest of the curve, because of this smoldering fire which persisted for nearly one-half hour after firing.

CO_2.—Figure 11 is a graphical summary of the CO_2 averages for all tests. It may be noted that the CO_2 was appreciably higher for the burner-equipped furnace, especially for the higher-burning rates. The CO_2 averages for the 5.8 pounds per hour rate were low on all three curves, because holes tended to form in the fuel bed due to small charges of fuel fired.

The curve representing average CO_2 from Illinois coal fired without

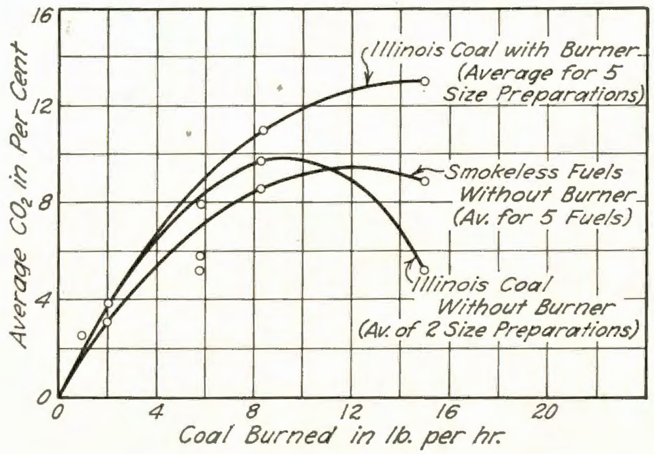

FIG. 11. AVERAGE CO_2 FOR ALL TESTS

the burner drops off sharply at the higher rates because holes formed in the fuel bed toward the end of the cycle. The CO_2 could have been maintained at a higher value by more frequent firing, but one purpose of the tests was to compare various fuels and methods of burning under similar conditions, and since a three-hour cycle had been used for tests with the burner, it was also used for the tests without it.

General Remarks.—The details of hand-fired apparatus for burning high-volatile coal smokelessly are not important, but the three fundamental requirements, listed at the beginning of this paper, must be met if smokeless combustion is to be achieved.

Sufficient secondary air may be supplied through suitably proportioned passages. However, if good efficiency is to be attained, the design must be such that the gases are not distilled too rapidly. A high rate of volatilization at any time in the cycle would require large passages for the supply of secondary air. These passages would supply excessive air after the end of the volatilization period. The volatilization rate may be definitely controlled by providing a coking chamber separate from the combustion chamber and controlling the air entering it by a suitably proportioned inlet port.

The secondary air may be thoroughly mixed with the volatile gases by introducing the air through vertical passages in the baffle wall which separates the coking chamber and the combustion chamber.

The temperature necessary to ignite the air-gas mixture is approximately 1300 deg. F., and can be attained by directing the mixture over the incandescent surfaces of the burning coke.

Conclusions.—Results of these tests together with others in which several types of high-volatile coal were burned in a down-draft furnace, indicate that a conventional furnace equipped with a down-draft burner, or any furnace, boiler, stove, or water heater having a suitable down-draft baffle would have the following improved characteristics:

(1) It would be capable of burning many types of high-volatile coal smokelessly.

(2) Special preparation of the coal would not be required for good results.

(3) Heat would be delivered immediately after firing due to the very quick response, even after several hours of hold-fire operation.

(4) It would be equally well adapted to burning high- or low-volatile coal.

(5) It would hold fire at least twice as long as the conventional furnace and would do so without overheating in mild weather.

XIV. NEW DEVELOPMENTS IN STEAM AND WATER HEATING SYSTEMS

R. E. FERRY*

1. *Early History.*—In discussing new developments in heating systems, the author may presume to exercise the privilege of determining for himself the approximate line of demarcation between what constitutes the old and the new; therefore, at the outset I am going to revert back more than 2000 years, if for no other purpose than to provide a background for what may be said about very recent developments.

The problem of providing comfort through heat is in no way changed from what it was at any time in the past. Stripped to its essentials, the science of heating involves the transfer of heat from its source, i.e., a fire, to the location where the human body happens to be. There has been, since the beginning of time, no change in the intensity or value of heat in a flame; the only change involved, therefore, is the development of more adequate means for the transfer of heat. The supplying of heat is thus a problem of transportation rather than of production.

If we trace the evolution of the transportation of heat for comfort purposes we start with the cave man, striking fire with a flint, igniting whatever dry underbrush happened to be nearby and transporting the burning embers to form the first hearth fire in his cave. At a much later date, the difficulties of striking fire led to the public office of "Keeper of the Fire," whose job it was to maintain constantly a flame from which private fires could be made. Coming on down through the centuries, we find records of the Greek prytaneum—the official hearth of the city, from which the fires of outlying colonies were kindled—a symbol of hospitality and a sacred bond between the mother city and the colony. Further advancement in the science of heating is found in the ruins of a recently excavated Greek palace on the island of Cyprus where a room was discovered to which water was conducted in three conduits and then boiled in order to supply steam heat for bedrooms on the second floor.

Later, the Romans added to the art of supplying comfort through the medium of heat by building hypocausts under their baths and later under their houses. Thus the basement was originated as the

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location for heating equipment. Fed by logs, the hypocaust delivered heat through openings connected to hollow bricks, along the floor and up the side walls.

Coming on further through history, we find the hearth fire in England, progressing from the stage of covered pyramids to carry the smoke through the roof, to the forerunner of the modern chimney, which meant the moving of the fire from the center of the room to the side wall.

Probably the earliest installation of a modern heating system of which there is a record was in the 18th century in France when Bonnemain constructed a hot water heating system in an incubator. Nineteenth century publications include a book by Tredgold, published in England in 1824, "Principles of Warming and Ventilating Public Buildings," and by Hood, entitled, "Treatise on Warming Buildings with Hot Water, Steam, and Hot Air," published in 1837.

The fathers of the central heating system, as we know it now, were the Nobel brothers (Alfred, Robert, and another brother), who left Sweden and set up a manufacturing business in Russia prior to the Civil War (about 1850); this was before the advent of the Mills boiler in this country, which was, I believe, the first sectional cast iron boiler. The Nobel brothers, who established in Russia a pump and steam engine manufacturing business, took a contract from the Czar to heat his palace with a forced hot water central heating system. This system, including the radiators, was constructed from pipe made by the Nobel brothers. These pioneers had a number of patents covering the design, manufacture, and installation of a central heating plant.

2. *Basic Types of Heating Systems.*—It may be helpful to present a brief picture describing the different basic types of heating systems of the present day, in which steam or hot water is used as the medium, and a description of the types of boilers, their firing methods, and the principal types of radiators.

One-pipe Steam Heating System

Until comparatively recently, one-pipe steam systems were looked upon as the low-cost system adaptable particularly to smaller types of residences. The single main running from the boiler to the radiators or convectors serves both as the steam supply and as the condensation return. In other words, as the steam condenses to water, the water returns to the boiler through the same pipe.

Two-pipe Steam or Vapor Heating System

The essential difference between a one-pipe and two-pipe steam system lies in the fact that in the two-pipe system the steam travels through one set of pipes and the condensate, or water, is returned through a separate set. This increases the cost of installation, although the two-pipe system operates at a lower pressure than the one-pipe system. Also, smaller pipes can be used. Both one-pipe and two-pipe systems can be used in houses without basements, provided a condensation pump is installed.

Gravity Hot-water System

Gravity hot-water systems require two sets of pipes, one to conduct the hot water to the radiators, and the other to return the cool water to the boiler for re-heating. The operation of this type of system depends upon the fact that hot water, being lighter than cold water, rises.

Forced Hot-water Heating System

There are two basic types—two-main and single-main systems for forced hot-water heating. The one-pipe forced hot-water heating system has made remarkably rapid strides very recently, induced by the fact that a great proportion of residential construction in the last two or three years has been of the low-cost type. The demands for low installed cost of the heating system, and for a heating system that responds instantly, accounts for the wide acceptance of this type of system.

3. *Types of Boilers and Firing Methods.**—The types of boilers and firing methods for domestic heating purposes may be briefly summarized as follows:

We are dealing here with the heating of homes and small apartments, rather than larger apartments, factories, and other types of large buildings.

The more important changes in boiler design in recent years have been along the lines of developing systems with automatic control, and the advent of automatic heat has made it necessary to design boilers on a more scientific basis than was required when hand-firing methods were prevalent. Domestic boilers are constructed either of cast iron or steel. Both of these types of boilers may be classified according to fuels: boilers for hand-firing with some automatic control, boilers for oil-firing, boilers for gas-firing, boilers for anthracite and bituminous

*"Developments in Domestic Heating," by L. N. Hunter, The National Radiator Company. (*Mechanical Engineering*, March, 1940.)

stoker-firing, and universal, or all-purpose, boilers designed especially for the application of more than one type of fuel.

With the rise in speculative building in recent years, the all-purpose boiler, or so-called conversion boiler, has been used to a large extent because of the fact that the builder does not know in advance the type of fuel which will be preferred by the ultimate buyer.

In steel boilers, the boiler shell itself is usually fabricated in one piece construction by electrically welding together steel plates of proper specifications. Most steel boilers are of a fire tube construction in which the hot flue gases pass through the tubes. Water tube construction is seldom used for domestic steel heating boilers. Such parts as doors, base, smokehood, and grates, commonly called the plate work, are usually made of cast iron.

Cast iron boilers consist of a number of cored sections assembled together and are of two types, namely, round and square, or sectional, boilers. Statistics published by the Department of Commerce indicate a steady rise during the last 12 or 13 years in the production of square sectional boilers and a decline in the production of round boilers. At the present time, square boilers represent more than 90 per cent of the total cast iron boilers produced. Both round and square boilers may be increased in size by adding sections. In the round boiler, the sections are added vertically and the grate area and space for combustion remain the same. Whereas, in sectional boilers, the sections are added horizontally and the grate area and the combustion space increase with the addition of sections.

Hand-fired boilers, whether made of cast iron or of steel, are frequently equipped with an electric motor which controls the rate of combustion in the fuel bed by operating the dampers which regulate the supply of air to the fuel, or a blower which also regulates the supply of air to the fuel bed. This apparatus is connected to a room thermostat which governs its operation depending upon the heat requirements of the building.

Boilers for oil-firing are of two types—one sold as a boiler only, designed for the application of different makes and types of oil burners; the other type is provided with burner equipment and sold as a complete unit, with the advantage that the burner and boiler are designed as integral parts.

Boilers for gas-firing are generally designed exclusively for gas, and usually are of the unit type, completely equipped with their own burners and controls. The same burners are used for natural, mixed, and manufactured gases, except that when mixed and manufactured gases are used, the ports on the burner are usually drilled smaller to prevent flash backs.

Stoker-fired boilers fired with either anthracite or bituminous coal stokers are usually an adaptation of the universal or oil-fired types. One of the continuing problems encountered in stoker-firing is the fly ash problem, and adequate provision is necessary to enable the removal of fly ash from the flues. There is a distinct trend toward special boilers for automatic-firing, whether oil- or stoker-fired, in which the boiler and burner equipment, as stated before, are designed as integral parts which provide the advantage of better coordination.

Probably the most important need which the boiler manufacturers have been forced to recognize in the last two or three years is that for boilers sufficiently small in size to meet the limited requirements of not only small, but well-insulated homes. Both of these factors tend to decrease the required capacity of the heating system. This fact is well demonstrated by the requirements of the I=B=R Research Home here at Urbana, a six-room, 2½ story brick veneer house, with full basement, which, due to proper insulation, showed a heat loss so low that the smallest boiler made by any manufacturer was still larger than was necessary for that particular house.

Before leaving the subject of boilers, let me make a brief reference to jackets, which, in keeping with the emphasis laid generally during the late '20s on styling, streamlining, and superfluities, began to make their appearance during that period and became general in the early '30s. One of the first boilers to be jacketed in this country was the water tube boiler. The jacket consisted of black sheet iron which covered the sides and top. The intervening space was filled with insulating material consisting of ¼-in. hair felt glued to the inner side of the sheet metal cover. Jackets are now generally accepted as an integral part of the residential boiler, but possibly the war economy which is rapidly affecting so many industries may result in classifying the jacket as a non-essential.

4. *Radiation.*—Early radiation, as used by Nobel, consisted of pipes, and later on the pipes were clustered in what is now known as a radiator. The sectional cast iron radiator made its appearance early in this century, and was based on the revolutionary Safford patent. A number of companies produced radiators based on this patent. The first radiators were very ornamental, in keeping with the spirit of the times—"the gay '90s"—and represented a work of art which was a credit to the pattern-making trade. With the passing of this era the floral and rococo features were removed, and the simple, plain, large column sections moved in.

About the middle '20s, a tubular type radiator made its appearance and practically overnight the column type radiators were replaced. This development first started in Europe under the Louis Corto patent, and was quickly picked up in this country.

Within the last six years, the simple, small-tube radiator has appeared. Radiator design has invariably followed the trend of the times. Slim-tube radiation lends itself to architectural simplicity, and its installation is in keeping with modern lines. One of the best examples of this type of semi-concealed, unobtrusive radiation is found in the I=B=R Research Home.

Of greatest importance is the fact that the radiator has been subdued in appearance but enhanced in efficiency.

No description of recent developments in radiation is complete without reference to convectors and convector-radiators. The forerunner of the present convector was the Gold Pin radiator. In its original application it was installed in the floor with two large inlet and outlet openings. The cold air under the floor became heated by the large amount of indirect surface contained in the radiator and rose into the room at the other end through the outlet grille. You can readily see the unsanitary condition that prevails in a unit installed in such a manner.

Another radiator of similar type, having a large amount of secondary surface, was introduced. The secondary surface was composed of random spiral turnings, such as is obtained when turning a bar of metal on a lathe. Random spirals were soldered to the prime surface of pipe, thereby giving the pipe additional radiating and convecting surface.

About 1930, the non-ferrous, hot cabinet, or free standing convector, made its first appearance. This originally consisted of a heating element composed of one or more copper tubes, over which copper fins were either pressed or soldered to form the extended secondary heating surface. This type of convector has continued its evolutionary development since that time. Other metals beside copper have been employed, such as aluminum and steel.

The demand for concealed radiation was met by the cast iron industry with the introduction of cast iron convectors. This form of radiation has seen many changes, and today it is characterized as a heating unit of cast iron, ranging from 6 in. to 12 in. of overall height and containing integral cast fins, with a proper distribution of secondary to prime surface. These convectors are installed in enclosures or concealed in the wall.

One might say that the present convector is the resurrection of the old Gold Pin radiator, except that a more sanitary way of installation is now employed.

5. *I=B=R Research Home.*—Much of what I have said up to this point has dealt with the past. There remain two specific subjects which I want to emphasize as being significant of the future.

In January of 1940, a group of 13 manufacturers of cast iron boilers and radiators determined that they would lend their money, time, and effort to building the most completely equipped laboratory house in the world for studying the efficiency of heating plants under actual operating conditions, and the effect of various systems of heating on environment and comfort.

Tangible evidence of this determination is found in the I=B=R Research Home here at Urbana. On behalf of those 13 manufacturers, who are members of The Institute of Boiler and Radiator Manufacturers, I desire to express a cordial invitation to all of you who have not visited the I=B=R Research Home to do so before you leave.

The basic purpose of the research program, which has been underwritten for a minimum period of three years, is to develop extensive and accurate data on the how and why of health and comfort in the home. The results of the research program will not only provide manufacturers with valuable information on the design of equipment, but will also provide heating contractors with new facts useful to them in their sales promotion work.

The staff of the Engineering Experiment Station at the University of Illinois has earned an enviable reputation for the work it has done in heating and ventilating research. It is for this reason that the Advisory Research Committee of The Institute of Boiler and Radiator Manufacturers decided to build the I=B=R Research Home adjacent to the campus of the University of Illinois. All of the supplementary research facilities of the Engineering Experiment Station as well as the School of Medicine are available for use in connection with the Research Home. Thus the entire correlated set-up for research is the best in the world.

The I=B=R Research Home is a typical six-room brick veneer house in the medium price range. The cubage of the main part of the house is 20 630, with 9700 cubic feet to be heated on the first and second floors, and 6020 cubic feet in the basement.

In the construction of the house, the I=B=R Advisory Research Committee recognized the fact that comfort and economy cannot be had simply by installing a heating system of excess capacity to care for deficiencies in the structure. Cold walls, drafts, and extreme temperature differentials between floor and ceiling, and between floors result from poor construction. And they must be eliminated if satisfactory atmospheric conditions are to be realized.

A thoroughly insulated house was therefore agreed upon as an essential of the Research Home. The walls were insulated with 3⅝ inches of mineral wool, protected on the inside with a vapor barrier of glazed asphalt paper. Rocklath was used as the plaster base, and wood sheathing was used and covered with a 15-pound building paper.

All windows were weather stripped. Storm windows have been purchased, but initial tests which began with the opening of the house on January 1, 1941, are being run without them.

The ceiling of the second floor is insulated with mineral wool, the same as the outside walls. The roof has regular wood sheathing and asphalt shingles.

Over 80 moisture measuring points are buried in all parts of the house. As records of moisture conditions are obtained, heating engineers will be able to design installations with the assurance that they will provide the expected service for the life of the house.

Naturally, temperatures at different points in the wall must be compared with moisture changes in order to have a clear picture of what happens. These temperatures are obtained by means of thermocouples, of which more than 100 have been installed in the outside walls. The temperatures measured with these thermocouples make possible the study of effect of wind, rain, and sunshine, or exposure.

Outside temperature and humidity are also recorded, as well as wind direction, velocity, and hours of sunshine.

Inside the house, thermocouples are located in each room, and temperatures may be recorded at the master panel in the basement. The temperatures are taken in each room at the floor and ceiling levels, and 30 and 60 inches from the floor. Most heating engineers know that the custom of placing the thermostat at a 60-inch level is not logical, since room occupancy is usually at a sitting position, which calls for a 30-inch control level. While well constructed houses such as the I=B=R Research Home have five degrees or less temperature difference between floor and ceiling, this problem is less important than it is in poorly constructed houses where differentials in excess of ten degrees exist. But, since the search is for "comfort efficiency," the facts will be permitted to prove the fallacy of regulating temperatures above the zone we live in. Then when we learn the temperature and humidity that we should have, we will endeavor to control it where we actually are.

Another important instrument included in the equipment for studying this environment is a globe thermometer, a comparative newcomer in the field of heating and ventilating research. This instrument is a black copper sphere that measures the mean radiant temperature, the final factor in assuring "comfort efficiency."

To some, this thorough study of structure and condition of air may seem beyond all practical use for heating contractors. But those who have followed current thinking of scientists, and the thorough research that is being carried out to increase the span of life and to raise the general health level of our people, recognize the value of this investigation immediately.

The Advisory Research Committee selected a one-pipe forced-circulation hot-water system, using an oil-burning boiler, for the first series of tests. Some of the factors influencing this decision were the flexibility of this system, its relatively low cost, and its increasing popularity. Four-column, 19-inch recessed radiators were selected because they fit nicely in a four-inch stud wall, and are compact and efficient.

Radiators are located under windows in keeping with current practice. However, tests may be made later to determine whether other locations may be more desirable.

Boiler efficiency is being carefully studied, as well as the effectiveness of the distribution and radiation system. Flow of water through the system, including each radiator, is being recorded. Temperatures of water entering and leaving the boiler are also being noted.

Thus it is evident that practical data will be obtained to evaluate various elements of hot water systems. In so doing, methods to increase efficiency and economy will be suggested.

Still another interesting phase of the investigation is the inside and outside chimney. Inside chimneys are known to be more efficient, but never has a direct test been made to determine just what an outside chimney costs. When this part of the investigation is completed builders will know how much extra it will cost to build an outside chimney, and can tell those who buy a house how much extra it will cost to operate their heating plant as well. Those who are architecturally-minded may not alter their plans, but those who think purely of an investment may discover that by using an inside chimney they

may obtain the desired "comfort efficiency" and make substantial savings.

While this description of the I=B=R Research Home may suggest that it is primarily a proving ground for a one-pipe forced-circulation hot-water system, that is not the case. Steam and vapor heating systems also have a place in the residential heating picture, and their field, too, will be determined as the test program is extended.

The schedule of tests will be determined as the current program develops by the Advisory Research Committee of The Institute of Boiler and Radiator Manufacturers. Serving on this committee are: J. P. Magos of Crane Co., Chairman; L. N. Hunter of The National Radiator Company; J. F. McIntire of United States Radiator Corporation; H. F. Randolph of International Heater Company, Inc.; and S. K. Smith of The H. B. Smith Company, Inc.

The program is being conducted under the general supervision of Professor A. P. Kratz and Professor M. K. Fahnestock of the Department of Mechanical Engineering of the University of Illinois.

The project is under the direct charge of W. S. Harris, assisted by R. J. Martin. Mr. Martin is living in the house where he takes the readings of the various instruments at frequent intervals.

6. *Boiler Rating Program.*—Time does not permit an extended summary of the development within the past 2½ years of the I=B=R Testing and Rating Code for Low Pressure Heating Boilers. The pertinent facts on this subject are that nearly all cast iron boilers for residences are now rated on a uniform basis, expressed in Gross I=B=R Output in B.t.u. and Net I=B=R Rating in B.t.u. and square feet of steam or water. Actual tests, under prescribed limitations, as set forth in the Code, are conducted by the manufacturer, and, before I=B=R Ratings are authorized, a competent committee of engineers checks all the details of the tests. The I=B=R Code comprises a common yardstick by which capacities of boilers are measured, and I=B=R Ratings represent a measure of performance which can be accepted with full confidence that the boiler will deliver the output which is published.

The I=B=R Code is now officially recognized as the accepted basis for determining boiler ratings by a number of Government agencies, including the Federal Housing Administration and the United States Housing Authority, also, the Heating, Piping, and Air Conditioning Contractors National Association.

Additional recognition of the work that the Institute has done in bringing order out of chaos in boiler ratings has recently been shown by the award of a certificate of honorable mention by a jury headed by Secretary of Commerce, Jesse H. Jones. The I=B=R boiler rating program was selected as one of seven outstanding trade association achievements accomplished during 1940 by more than 2000 national associations. This award was presented to The Institute of Boiler and Radiator Manufacturers "for its achievement in developing common standards of performance of boilers used in residential heating, and reliable methods of selecting proper sizes and types for heating comfort."

7. *Conclusion.*—Now, to get back briefly to our original subject.

What are the criteria by which the importance of new developments in any industry are to be evaluated? What is the most important gauge or yardstick by which an industry's progress should be measured?

A progressive and forward looking industry will strive to reduce costs of manufacture and distribution, reduce the weight of its product to facilitate shipping, handling, and installation, streamline its product to enhance the eye-value, standardize and simplify the lines produced so as to reduce the cost of manufacture, warehousing, and distribution, etc., etc. But the industry which profits most in insuring an ever-expanding market is the industry which delivers more service and efficiency, with greater comfort and ease of operation, for the dollars which the consumer is willing or able to spend.

It becomes almost monotonous to hear the automobile constantly referred to as the industry which has developed an ever-widening market because of the progress which it has made in achieving a gradually ascending scale of efficient and effortless output of its product, coupled with a marked decrease in cost to the consumer. The pickup, speedy response, ease of control, comfort, reduced cost of operation, and other factors which are expected and obtained in today's $1000 car were never dreamed of even three or four years ago in cars at any price. So it is natural that we refer to that industry as a paragon of virtue in having given the ultimate to the consumer and thus continued to build an ever increasing market.

Let us apply some of these same terms to the domestic heating industry and see what has been done recently—the same terms of pickup, speedy response, ease of control, comfort, and cost of operation. They can be matched, term for term, and in a ratio of progress which stamps the members of this heating industry with the hallmark

of ingenuity and accomplishment which the consumer is recognizing more and more widely with the resurgence of building and modernizing which is sweeping over the country.

Omitting for the moment the use of those poly-syllabic terms, such as, temperature gradients and transmission coefficients, convection and condensation, radiation and relative humidity, thermocouples and thermostats, eupatheoscopes and equivalent temperatures, B.t.u. and dry bulb temperatures, barometers and biochemical reactions, insulation and infiltration, sensible heat losses and latent heat gains, equilibrium conditions and aquastats, thermodynamics and cryotherapy, etc., let me refer to some of the recent contributions of the heating equipment and accessory manufacturers to the cause of Human Comfort.

Reduced to simplest terms, the prime function of a heating system is to change an uncomfortable indoor environment to a comfortable one and to do it instantly, evenly, quietly, cleanly, and economically. The old order of supplying heating comfort on the installment basis, whenever the system may have reached its peak of efficiency and with temperatures within the same room varying as much as 25 degrees, no longer suffices. Speed is essential. Instant response to the touch of a finger on the conveniently located controls is demanded. Evenness of temperature horizontally and vertically throughout the room and the house are now expected. The meeting of these requirements in the average home, where low cost of installation and operation is a factor, is increasing the number of forced-circulation hot-water systems which are being installed.

The development of more sensitive controls, the grading of fuels, better insulation both of the house and the heating plant, and the improvement in servicing are only a few of the many factors which today help to provide a greater return on the heating dollar.

Zoning of a house in order to provide variations in temperature to suit the individual preferences of the occupants of different rooms is easily accomplished today, both with hot water and steam.

Built into the modern boiler is a fire-travel three times the length of the boiler itself so that every ounce of available heat is transferred for use. In the case of oil-fired units, the principle of sustained heat has been so perfected that the boiler will continue to transfer heat even after the flame has been cut off. The operation of the gas-fired boiler is completely automatic.

In mentioning these latter features, I do not discount the developments which have occurred in connection with the use of coal. New models of stokers are so constructed that they will operate almost noiselessly; motors, and working parts are generally enclosed to protect them from dirt and dust; the speed of the feed worm is variable and can be changed quickly; progress has been made in designing stokers so as to require less attention; safety controls have been added.

However, to you who are primarily interested in coal, I would leave a challenge. Your own interests demand that you keep before you a realization that the public will continue to require heating equipment which embodies the maximum degree of all of those attributes which we referred to a little while ago, i.e., pickup, speedy response, ease of control, maximum of comfort, and minimum of cost of installation and operation. The ingenuity and progressive record of you whose interests are involved in the use of coal is a mark of achievement. In meeting the competition from other fuels, however, you will be required to continue and expand your research and investigations into the use of coal-burning equipment. The cooperation and assistance of the boiler and radiator manufacturers may be counted on in your pursuit of knowledge that can be of benefit to all of us.